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FRESHWATER BIOLOGY AND POLLUTION ECOLOGY

TRAINING MANUAL

Environmental Protection Agency

April 1975

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FRESHWATER BIOLOGY AND POLLUTION ECOLOGY

TRAINING MANUAL

U.S. ENVIRONMENTAL PROTECTION AGENCY

WATER PROGRAM OPERATIONS

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FRESHWATER BIOLOGY

This course is designed as an introduction to aquatic biology for sanitary engineers, scientists, and others who are involved in freshwater pollution studies, surveillance, and control. Biologists new to the field of aquatic biology and pollution problems may find it useful for orientation.

AND

FRESHWATER POLLUTION ECOLOGY

This course is offered for aquatic biologists or persons with comparable experience concerned with and/or involved in the application of biological principles, techniques and parameters to pollution studies and abatement programs.

ENVIRONMENTAL PROTECTION AGENCY
Office of Water Program Operations
TRAINING PROGRAM

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SURVEY OF THE BIOTA

The first half of this manual is a synoptic review of the components of the aquatic community to aid the observer in recognizing many common types of organisms encountered both in the field, laboratory, and treatment facilities.

A comprehension of the system of biological nomenclature and ecological classifications, is basic to an understanding of aquatic life communities. The first exercise in ecology is systematics. Application of systematics will depend on one's background, present limitations, and program objectives.

Systematics, broadly defined, is the study of the diversity of organisms. In connotation it is a wedding between taxonomy and ecology. In applied biology or ecology, good systematics is indispensable and is an immensely useful system of information storage and retrieval. The following definitions are basic.

SYSTEMATICS: "The scientific study of the kinds and diversity of organisms and of any and all relationships among them."

CLASSIFICATION: "The ordering of organisms into groups (or sets) on the basis of their relationships; that is, of their associations by contiguity, similarity, or both."

TAXONOMY: "The theoretical study of classification, including its bases, principles, procedures, and rules."

IDENTIFICATION: "The use of a key (or key substitute like an expert) to place an unknown organism into a specific taxonomic rank."

✓

THE AQUATIC ENVIRONMENT

Part 1: The Nature and Behavior of Water

I INTRODUCTION

The earth is physically divisible into the lithosphere or land masses, and the hydrosphere which includes the oceans, lakes, streams, and subterranean waters.

A Upon the hydrospere are based a number of sciences which represent different approaches. Hydrology is the general science of water itself with its various special fields such as hydrography, hydraulics, etc. These in turn merge into physical chemistry and chemistry.

B Limnology and oceanography combine aspects of all of these, and deal not only with the physical liquid water and its various naturally occurring solutions and forms, but also with living organisms and the infinite interactions that occur between them and their environment.

C Water quality management, including pollution control, thus looks to all branches of aquatic science in efforts to coordinate and improve man's relationship with his aquatic environment.

II SOME FACTS ABOUT WATER

A Water is the only abundant liquid on our planet. It has many properties most unusual for liquids, upon which depend most of the familiar aspects of the world about us as we know it. (See Table 1)

TABLE 1

UNIQUE PROPERTIES OF WATER

Property	Significance
Highest heat capacity (specific heat) of any solid or liquid (except NH_3)	Stabilizes temperatures of organisms and geographical regions
Highest latent heat of fusion (except NH_3)	Thermostatic effect at freezing point
Highest heat of evaporation of any substance	Important in heat and water transfer of atmosphere
The only substance that has its maximum density as a liquid (4°C)	Fresh and brackish waters have maximum density above freezing point. This is important in vertical circulation pattern in lakes.
Highest surface tension of any liquid	Controls surface and drop phenomena, important in cellular physiology
Dissolves more substances in greater quantity than any other liquid	Makes complex biological system possible. Important for transportation of materials in solution.
Pure water has the highest di-electric constant of any liquid	Leads to high dissociation of inorganic substances in solution
Very little electrolytic dissociation	Neutral, yet contains both H^+ and OH^- ions
Relatively transparent	Absorbs much energy in infra red and ultra violet ranges, but little in visible range. Hence "colorless"

B Physical Factors of Significance

1 Water substance

Water is not simply "H_2O" but in reality is a mixture of some 33 different substances involving three isotopes each of hydrogen and oxygen (ordinary hydrogen H^1, deuterium H^2, and tritium H^3; ordinary oxygen O^{16}, oxygen 17, and oxygen 18) plus 15 known types of ions. The molecules of a water mass tend to associate themselves as polymers rather than to remain as discrete units. (See Figure 1)

SUBSTANCE OF PURE WATER

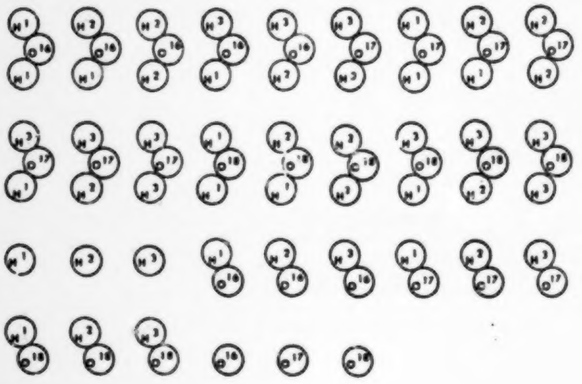

Figure 1

2 Density

a Temperature and density: Ice. Water is the only known substance in which the solid state will float on the liquid state. (See Table 2) This ensures that ice usually forms on top of a body of water and tends to insulate the remaining water mass from further loss of heat. Did ice sink, there could be little or no carryover of aquatic life from season to season in the higher latitudes. Frazil or needle ice forms colloidally at a few thousandths of a degree below 0° C. It is adhesive and may build up on submerged objects as "anchor ice", but it is still typical ice (ice I).

TABLE 2

EFFECTS OF TEMPERATURE ON DENSITY OF PURE WATER AND ICE*

Temperature (°C)	Density	
	Water	Ice**
-10	.99815	.9397
- 8	.99869	.9360
- 6	.99912	.9020
- 4	.99945	.9277
- 2	.99970	.9229
0	.99987----	.9168
2	.99997	
4	1.00000	
6	.99997	
8	.99988	
10	.99973	
20	.99823	
40	.99225	
60	.98324	
80	.97183	
100	.95838	

* Tabular values for density, etc., represent estimates by various workers rather than absolute values, due to the variability of water.

** Regular ice is known as "ice I". Four or more other "forms" of ice are known to exist (ice II, ice III, etc.), having densities at 1 atm. pressure ranging from 1.1595 to 1.67. These are of extremely restricted occurrence and may be ignored in most routine operations.

1) Seasonal increase in solar radiation annually warms surface waters in summer while other factors result in winter cooling. The density differences resulting establish two classic layers: the epilimnion or surface layer, and the hypolimnion or lower layer, and in between is the thermocline or shear-plane.

2) While for certain theoretical purposes a "thermocline" is defined as a zone in which the temperature changes one degree centigrade for each meter of depth, in practice, any transitional layer between two relatively stable masses of water of different temperatures may be regarded as a thermocline.

3) Obviously the greater the temperature differences between epilimnion and hypolimnion and the sharper the gradient in the thermocline, the more stable will the situation be.

4) From information given above, it should be evident that while the temperature of the hypolimnion rarely drops much below 4° C, the epilimnion may range from 0° C upward.

5) When epilimnion and hypolimnion achieve the same temperature, stratification no longer exists. The entire body of water behaves hydrologically as a unit, and tends to assume uniform chemical and physical characteristics. Even a light breeze may then cause the entire body of water to circulate. Such events are called overturns, and usually result in water quality changes of considerable physical, chemical, and biological significance. Mineral-rich water from the hypolimnion, for example, is mixed with oxygenated water from the epilimnion. This usually triggers a sudden growth or "bloom" of plankton organisms.

6) When stratification is present, however, each layer behaves relatively independently, and significant quality differences may develop.

7) Thermal stratification as described above has no reference to the size of the water mass; it is found in oceans and puddles.

b The relative densities of the various isotopes of water influence its molecular composition. For example, the lighter O_{16} tends to go off first in the process of evaporation, leading to the relative enrichment of air by O_{16} and the enrichment of water by O_{17} and O_{18}. This can lead to a measurably higher O_{18} content in warmer climates. Also, the temperature of water in past geologic ages can be closely estimated from the ratio of O_{18} in the carbonate of mollusc shells.

c Dissolved and/or suspended solids may also affect the density of natural water masses (see Table 3)

TABLE 3
EFFECTS OF DISSOLVED SOLIDS ON DENSITY

Dissolved Solids (Grams per liter)	Density (at 4° C)
0	1.00000
1	1.00085
2	1.00169
3	1.00251
10	1.00818
35 (mean for sea water)	1.02822

d Types of density stratification

1) Density differences produce stratification which may be permanent, transient, or seasonal.

2) Permanent stratification exists for example where there is a heavy mass of brine in the deeper areas of a basin which does not respond to seasonal or other changing conditions.

3) Transient stratification may occur with the recurrent influx of tidal water in an estuary for example, or the occasional influx of cold muddy water into a deep lake or reservoir.

4) Seasonal stratification is typically thermal in nature, and involves the annual establishment of the epilimnion, hypolimnion, and thermocline as described above.

5) Density stratification is not limited to two-layered systems; three, four, or even more layers may be encountered in larger bodies of water.

e A "plunge line" (sometimes called "thermal line") may develop at the mouth of a stream. Heavier water flowing into a lake or reservoir plunges below the lighter water mass of the epiliminium to flow along at a lower level. Such a line is usually marked by an accumulation of floating debris.

f Stratification may be modified or entirely suppressed in some cases when deemed expedient, by means of a simple air lift.

3 The viscosity of water is greater at lower temperatures (see Table 4).

This is important not only in situations involving the control of flowing water as in a sand filter, but also since overcoming resistance to flow generates heat, it is significant in the heating of water by internal friction from wave and current action. Living organisms more easily support themselves in the more viscous (and also denser) cold waters of the arctic than in the less viscous warm waters of the tropics. (See Table 4).

TABLE 4

VISCOSITY OF WATER (In millipoises at 1 atm)

	Dissolved solids in g/L			
Temp. ° C	0	5	10	30
-10	26.0	----	----	----
- 5	21.4	----	----	----
0	17.94	18.1	18.24	18.7
5	15.19	15.3	15.5	16.0
10	13.10	13.2	13.4	13.8
30	8.00	8.1	8.2	8.6
100	2.84	----	----	----

4 Surface tension has biological as well as physical significance. Organisms whose body surfaces cannot be wet by water can either ride on the surface film or in some instances may be "trapped" on the surface film and be unable to re-enter the water.

5 Heat or energy

Incident solar radiation is the prime source of energy for virtually all organic and most inorganic processes on earth. For the earth as a whole, the total amount (of energy) received annually must exactly balance that lost by reflection and radiation into space if climatic and related conditions are to remain relatively constant over geologic time.

a For a given body of water, immediate sources of energy include in addition to solar irradiation: terrestrial heat, transformation of kinetic energy (wave and current action) to heat, chemical and biochemical reactions, convection from the atmosphere, and condensation of water vapor.

b The proportion of light reflected depends on the angle of incidence, the temperature, color, and other qualities of the water; and the presence or absence of films of lighter liquids such as oil. In general, as the depth increases arithmetically, the light tends to decrease geometrically. Blues, greens, and yellows tend to penetrate most deeply while ultra violet, violets, and orange-reds are most quickly absorbed. On the order of 90% of the total illumination which penetrates the surface film is absorbed in the first 10 meters of even the clearest water, thus tending to warm the upper layers.

6 Water movements

a Waves or rhythmic movement

1) The best known are traveling waves caused by wind. These are effective only against objects near the surface. They have little effect on the movement of large masses of water.

2) Seiches

Standing waves or seiches occur in lakes, estuaries, and other enclosed bodies of water, but are seldom large enough to be observed. An "internal wave or seich" is an oscillation in a submersed mass of water such as a hypolimnion, accompanied by compensating oscillation in the overlying water so that no significant change in surface level is detected. Shifts in submerged water masses of this type can have severe effects on the biota and also on human water uses where withdrawals are confined to a given depth. Descriptions and analyses of many other types and sub-types of waves and wave-like movements may be found in the literature.

b Tides

1) Tides are the longest waves known, and are responsible for the once or twice a day rythmic rise and fall of the ocean level on most shores around the world.

2) While part and parcel of the same phenomenon, it is often convenient to refer to the rise and fall of the water level as "tide," and to the resulting currents as "tidal currents."

3) Tides are basically caused by the attraction of the sun and moon on water masses, large and small; however, it is only in the oceans and possibly certain of the larger lakes that true tidal action has been demonstrated. The patterns of tidal action are enormously complicated by local topography, interaction with seiches, and other factors. The literature on tides is very large.

c Currents (except tidal currents) are steady arythmic water movements which have had major study only in oceanography although they are most often observed in rivers and streams. They are primarily concerned with the translocation of water masses. They may be generated internally by virtue of density changes, or externally by wind or terrestrial topography. Turbulence phenomena or eddy currents are largely responsible for lateral mixing in a current. These are of far more importance in the economy of a body of water than mere laminar flow.

d **Coriolis** force is a result of interaction between the rotation of the earth, and the movement of masses or bodies on the earth. The net result is a slight tendency for moving objects to veer to the right in the northern hemisphere, and to the left in the southern hemisphere. While the result in fresh waters is usually negligible, it may be considerable in marine waters. For example, other factors permitting, there is a tendency in estuaries for fresh waters to move toward the ocean faster along the right bank, while salt tidal waters tend to intrude farther inland along the left bank. Effects are even more dramatic in the open oceans.

e **Langmuir circulation** (or L. spirals) is the interlocking rotation of somewhat cylindrical masses of surface water under the influence of wind action. The axes of the cylinders are parallel to the direction of the wind.

To somewhat oversimplify the concept, a series of adjoining cells might be thought of as chains of interlocking gears in which at every other contact the teeth are rising while at the alternate contacts, they are sinking (Figure 2).

The result is elongated masses of water rising or sinking together. This produces the familiar "wind rows" of foam, flotsam and jetsam, or plankton often seen streaking windblown lakes or oceans. Certain zoo-plankton struggling to maintain a position near the surface tend to collect in the down current between two Langmuir cells, causing such an area to be called the "red dance", while the clear upwelling water between is the "blue dance".

This phenomenon may be important in water or plankton sampling on a windy day.

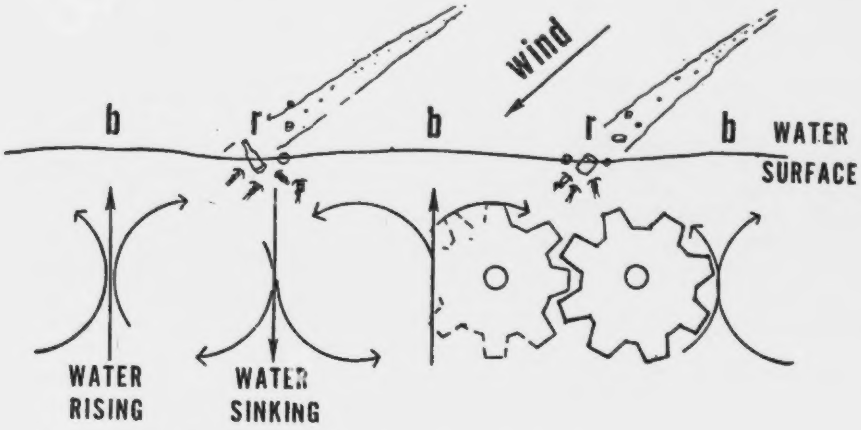

Figure 2. Langmuire Spirals
b. Blue dance, water rising. r. Red dance, water sinking, floating or swimming objects concentrated.

6 The pH of pure water has been determined between 5.7 and 7.01 by various workers. The latter value is most widely accepted at the present time. Natural waters of course vary widely according to circumstances.

C The elements of hydrology mentioned above represent a selection of some of the more conspicuous physical factors involved in working with water quality. Other items not specifically mentioned include: molecular structure of waters, interaction of water and radiation, internal pressure, acoustical characteristics, pressure-volume-temperature relationships, refractivity, luminescence, color, dielectrical characteristics and phenomena, solubility, action and interactions of gases, liquids and solids, water vapor, phenomena of hydrostatics and hydrodynamics in general.

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This outline was prepared by H. W. Jackson, Chief Biologist, National Training Center, Water Programs Operations, EPA, Cincinnati, OH 45268.

Descriptors:
Aquatic Environment, Estuarine Environment, Lentic Environment, Lotic Environment, Currents, Marshes, Limnology, Water Properties

THE AQUATIC ENVIRONMENT

Part 2: The Aquatic Environment as an Ecosystem

I INTRODUCTION

Part 1 introduced the lithosphere and the hydrosphere. Part 2 will deal with certain general aspects of the biosphere, or the sphere of life on this earth, which photographs from space have shown is a finite globe in infinite space.

This is the habitat of man and the other organisms. His relationships with the aquatic biosphere are our common concern.

II THE BIOLOGICAL NATURE OF THE WORLD WE LIVE IN

A We can only imagine what this world must have been like before there was life.

B The world as we know it is largely shaped by the forces of life.

1 Primitive forms of life created organic matter and established soil.

2 Plants cover the lands and enormously influence the forces of erosion.

3 The nature and rate of erosion affect the redistribution of materials (and mass) on the surface of the earth (topographic changes).

4 Organisms tie up vast quantities of certain chemicals, such as carbon and oxygen.

5 Respiration of plants and animals releases carbon dioxide to the atmosphere in influential quantities.

6 CO_2 affects the heat transmission of the atmosphere.

C Organisms respond to and in turn affect their environment. Man is one of the most influential.

III ECOLOGY IS THE STUDY OF THE INTERRELATIONSHIPS BETWEEN ORGANISMS, AND BETWEEN ORGANISMS AND THEIR ENVIRONMENT.

A The ecosystem is the basic functional unit of ecology. Any area of nature that includes living organisms and nonliving substances interacting to produce an exchange of materials between the living and nonliving parts constitutes an ecosystem. (Odum, 1959)

1 From a structural standpoint, it is convenient to recognize four constituents as composing an ecosystem (Figure 1).

a Abiotic NUTRIENT MINERALS which are the physical stuff of which living protoplasm will be synthesized.

b Autotrophic (self-nourishing) or PRODUCER organisms. These are largely the green plants (holophytes), but other minor groups must also be included (See Figure 2). They assimilate the nutrient minerals, by the use of considerable energy, and combine them into living organic substance.

c Heterotrophic (other-nourishing) CONSUMERS (holozoic), are chiefly the animals. They ingest (or eat) and digest organic matter, releasing considerable energy in the process.

d Heterotrophic REDUCERS are chiefly bacteria and fungi that return complex organic compounds back to the original abiotic mineral condition, thereby releasing the remaining chemical energy.

2 From a functional standpoint, an ecosystem has two parts (Figure 2)

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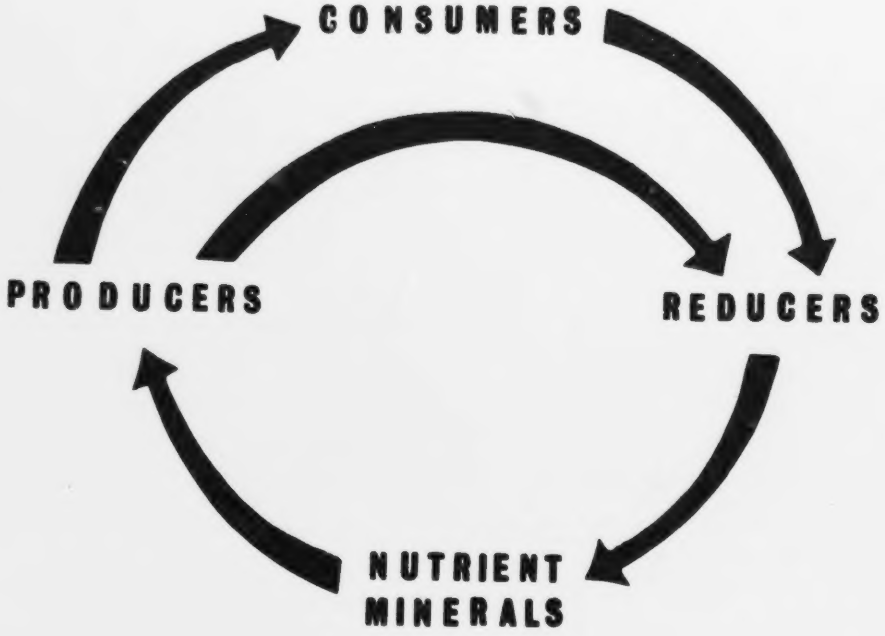


FIGURE 1

a The autotrophic or producer organisms, which construct organic substance.

b The heterotrophic or consumer and reducer organisms which destroy organic substance.

3 Unless the autotrophic and heterotrophic phases of the cycle approximate a dynamic equilibrium, the ecosystem and the environment will change.

B Each of these groups includes simple, single-celled representatives, persisting at lower levels on the evolutionary stems of the higher organisms. (Figure 2)

1 These groups span the gaps between the higher kingdoms with a multitude of transitional forms. They are collectively called the PROTISTA.

2 Within the protista, two principal subgroups can be defined on the basis of relative complexity of structure.

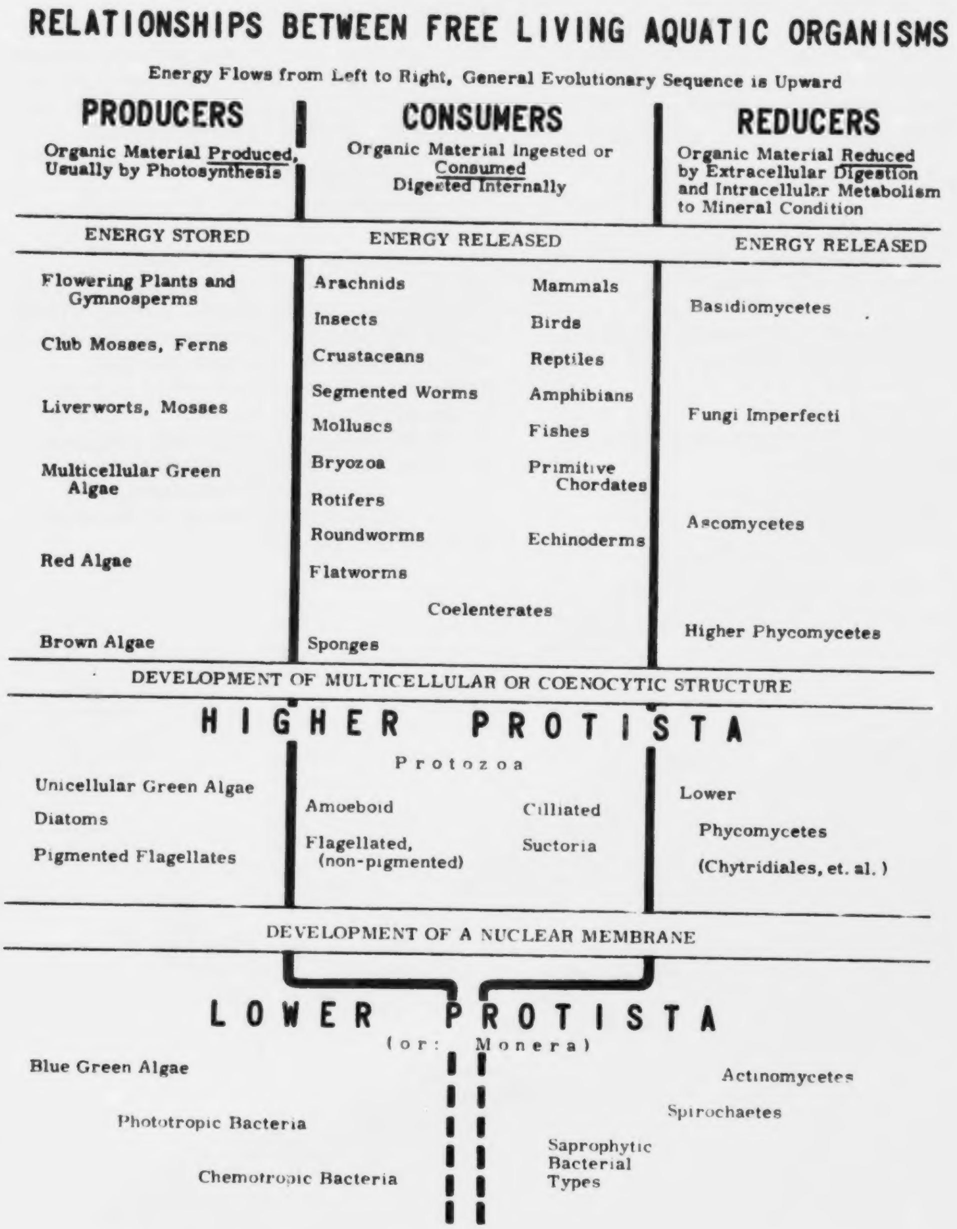
a The bacteria and blue-green algae, lacking a nuclear membrane may be considered as the lower protista (or Monera).

b The single-celled algae and protozoa are best referred to as the Higher Protista.

C Distributed throughout these groups will be found most of the traditional "phyla" of classic biology.

IV FUNCTIONING OF THE ECOSYSTEM

A A food chain is the transfer of food energy from plants through a series of organisms with repeated eating and being eaten. Food chains are not isolated sequences but are interconnected.



RELATIONSHIPS BETWEEN FREE LIVING AQUATIC ORGANISMS

Energy Flows from Left to Right, General Evolutionary Sequence is Upward

PRODUCERS	**CONSUMERS**		**REDUCERS**
Organic Material Produced, Usually by Photosynthesis	Organic Material Ingested or Consumed Digested Internally		Organic Material Reduced by Extracellular Digestion and Intracellular Metabolism to Mineral Condition
ENERGY STORED	ENERGY RELEASED		ENERGY RELEASED
Flowering Plants and Gymnosperms	Arachnids	Mammals	Basidiomycetes
	Insects	Birds	
Club Mosses, Ferns	Crustaceans	Reptiles	
	Segmented Worms	Amphibians	
Liverworts, Mosses	Molluscs	Fishes	Fungi Imperfecti
Multicellular Green Algae	Bryozoa	Primitive Chordates	
	Rotifers		
	Roundworms	Echinoderms	Ascomycetes
Red Algae	Flatworms		
	Coelenterates		
Brown Algae	Sponges		Higher Phycomycetes

DEVELOPMENT OF MULTICELLULAR OR COENOCYTIC STRUCTURE

HIGHER PROTISTA

	Protozoa		
Unicellular Green Algae	Amoeboid	Cilliated	Lower Phycomycetes (Chytridiales, et. al.)
Diatoms	Flagellated, (non-pigmented)	Suctoria	
Pigmented Flagellates			

DEVELOPMENT OF A NUCLEAR MEMBRANE

LOWER PROTISTA

(or: Monera)

Blue Green Algae	Actinomycetes
Phototropic Bacteria	Spirochaetes
Chemotropic Bacteria	Saprophytic Bacterial Types

Bl. ECO. pl. 2a. 1. 69

FIGURE 2

B A food web is the interlocking pattern of food chains in an ecosystem. (Figures 3, 4) In complex natural communities, organisms whose food is obtained by the same number of steps are said to belong to the same trophic (feeding) level.

C Trophic Levels

1 First - Green plants (producers) (Figure 5) fix biochemical energy and synthesize basic organic substances. This is "primary production".

2 Second - Plant eating animals (herbivores) depend on the producer organisms for food.

3 Third - Primary carnivores, animals which feed on herbivores.

4 Fourth - Secondary carnivores feed on primary carnivores.

5 Last - Ultimate carnivores are the last or ultimate level of consumers.

D Total Assimilation

The amount of energy which flows through a trophic level is distributed between the production of biomass (living substance), and the demands of respiration (internal energy use by living organisms) in a ratio of approximately 1:10.

E Trophic Structure of the Ecosystem

The interaction of the food chain phenomena (with energy loss at each transfer) results in various communities having definite trophic structure or energy levels. Trophic structure may be measured and described either in terms of the standing crop per unit area or in terms of energy fixed per unit area per unit time at successive trophic levels. Trophic structure and function can be shown graphically by means of ecological pyramids (Figure 5).

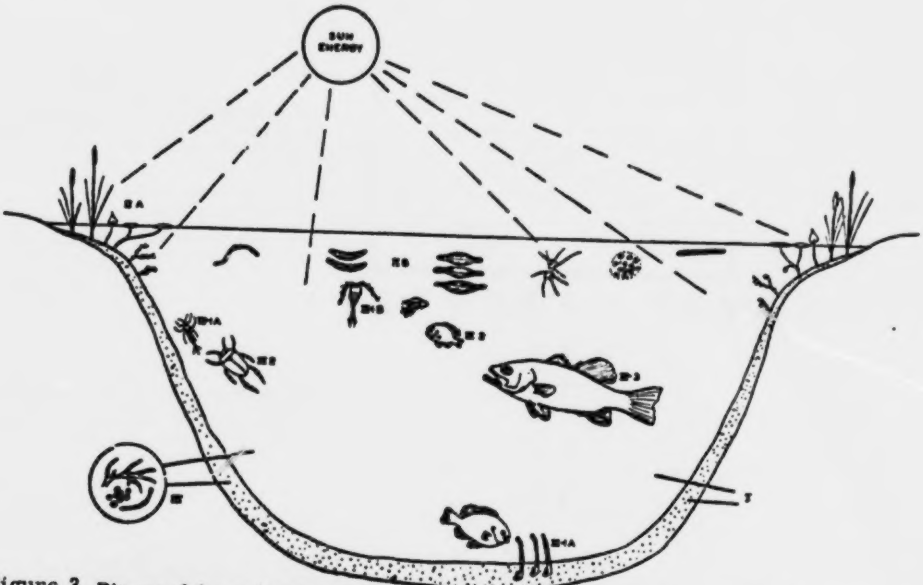
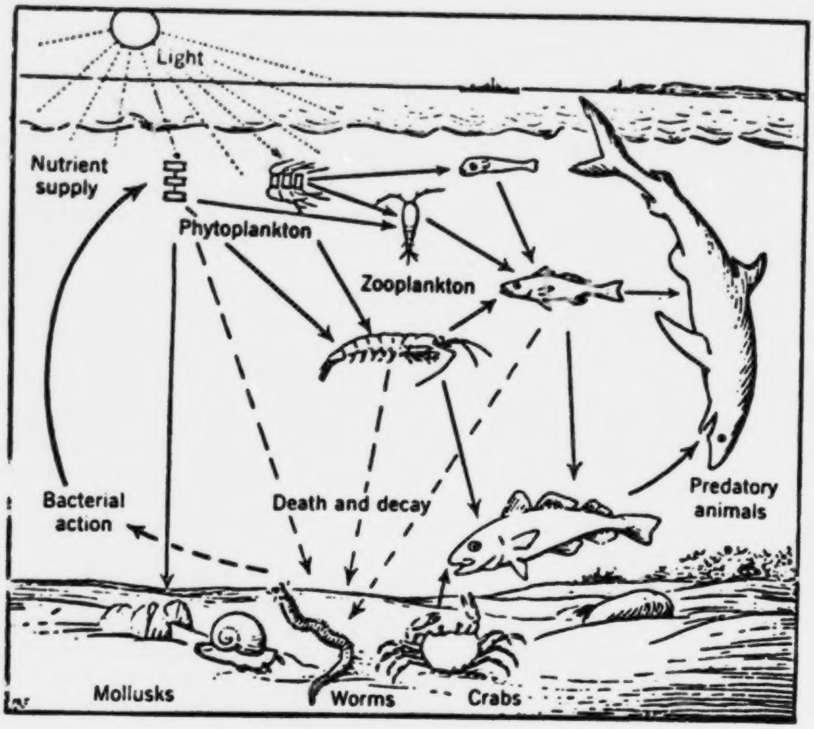


Figure 3. Diagram of the pond ecosystem. Basic units are as follows: I, abiotic substances–basic inorganic and organic compounds; IIA, producers–rooted vegetation; IIB, producers–phytoplankton; III-1A, primary consumers (herbivores)–bottom forms; III-1B, primary consumers (herbivores)–zooplankton; III-2, secondary consumers (carnivores); III-3, tertiary consumers (secondary carnivores); IV, decomposers–bacteria and fungi of decay.


Light
Nutrient supply
Phytoplankton
Zooplankton
Bacterial action
Death and decay
Predatory animals
Mollusks
Worms
Crabs

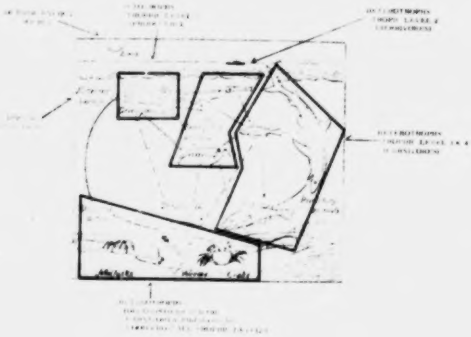


Figure 4. A MARINE ECOSYSTEM (After Clark, 1954 and Patten, 1966)

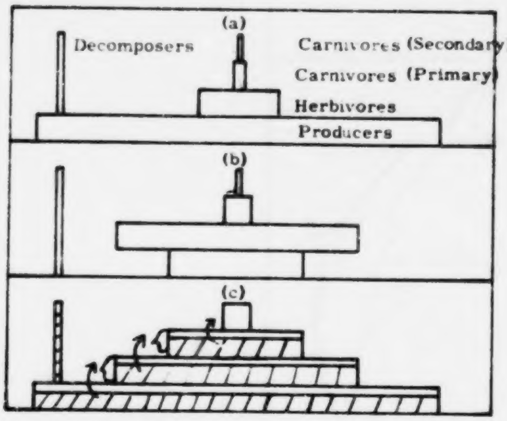


Figure 5. HYPOTHETICAL PYRAMIDS of (a) Numbers of individuals, (b) Biomass, and (c) Energy (Shading Indicates Energy Loss).

V BIOTIC COMMUNITIES

A Plankton are the macroscopic and microscopic animals, plants, bacteria, etc., floating free in the open water. Many clog filters, cause tastes, odors, and other troubles in water supplies. Eggs and larvae of larger forms are often present.

1 Phytoplankton are plant-like. These are the dominant producers of the waters, fresh and salt, "the grass of the seas".

2 Zooplankton are animal-like. Includes many different animal types, range in size from minute protozoa to gigantic marine jellyfishes.

B Periphyton (or Aufwuchs) - The communities of microscopic organisms associated with submerged surfaces of any type or depth. Includes bacteria, algae, protozoa, and other microscopic animals, and often the young or embryonic stages of algae and other organisms that normally grow up to become a part of the benthos (see below). Many planktonic types will also adhere to surfaces as periphyton, and some typical periphyton may break off and be collected as plankters.

C Benthos are the plants and animals living on, in, or closely associated with the bottom. They include plants and invertebrates.

D Nekton are the community of strong aggressive swimmers of the open waters, often called pellagic. Certain fishes, whales, and invertebrates such as shrimps and squids are included here.

E The marsh community is based on larger "higher" plants, floating and emergent. Both marine and freshwater marshes are areas of enormous biological production. Collectively known as "wetlands", they bridge the gap between the waters and the dry lands.

VI PRODUCTIVITY

A The biological resultant of all physical and chemical factors in the quantity of life that may actually be present. The ability to produce this "biomass" is often referred to as the "productivity" of a body of water. This is neither good nor bad per se. A water of low productivity is a "poor" water biologically, and also a relatively "pure" or "clean" water; hence desirable as a water supply or a bathing beach. A productive water on the other hand may be a nuisance to man or highly desirable. It is a nuisance if foul odors and/or weed-chocked waterways result, it is desirable if bumper crops of bass, catfish, or oysters are produced. Open oceans have a low level of productivity in general.

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Descriptors:
Aquatic Environment, Estuarine Environment, Lentic Environment, Lotic Environment, Currents, Marshes, Limnology, Water Properties

THE AQUATIC ENVIRONMENT

Part 3. The Freshwater Environment

I INTRODUCTION

The freshwater environment as considered herein refers to those inland waters not detectably diluted by ocean waters, although the lower portions of rivers are subject to certain tidal flow effects.

Certain atypical inland waters such as saline or alkaline lakes, springs, etc., are not treated, as the main objective here in typical inland water.

All waters have certain basic biological cycles and types of interactions most of which have already been presented, hence this outline will concentrate on aspects essentially peculiar to fresh inland waters.

II PRESENT WATER QUALITY AS A FUNCTION OF THE EVOLUTION OF FRESH WATERS

A The history of a body of water determines its present condition. Natural waters have evolved in the course of geologic time into what we know today.

B Streams

In the course of their evolution, streams in general pass through four stages of development which may be called: birth, youth, maturity, and old age.

These terms or conditions may be employed or considered in two contexts: temporal, or spatial. In terms of geologic time, a given point in a stream may pass through each of the stages described below or: at any given time, these various stages of development can be loosely identified in successive reaches of a stream traveling from its headwaters to base level in ocean or major lake.

1 Establishment or birth. This might be a "dry run" or headwater stream-bed, before it had eroded down to the level of ground water.

During periods of run-off after a rain or snow-melt, such a gulley would have a flow of water which might range from torrential to a mere trickle. Erosion may proceed rapidly as there is no permanent aquatic flora or fauna to stabilize streambed materials. On the other hand, terrestrial grass or forest growth may retard erosion. When the run-off has passed, however, the "streambed" is dry.

2 Youthful streams. When the streambed is eroded below the ground water level, spring or seepage water enters, and the stream becomes permanent. An aquatic flora and fauna develops and water flows the year round. Youthful streams typically have a relatively steep gradient, rocky beds, with rapids, falls, and small pools.

3 Mature streams. Mature streams have wide valleys, a developed flood plain, are deeper, more turbid, and usually have warmer water, sand, mud, silt, or clay bottom materials which shift with increase in flow. In their more favorable reaches, streams in this condition are at a peak of biological productivity. Gradients are moderate, riffles or rapids are often separated by long pools.

4 In old age, streams have approached geologic base level, usually the ocean. During flood stage they scour their beds and deposit materials on the flood plain which may be very broad and flat. During normal flow the channel is refilled and many shifting bars are developed.

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(Under the influence of man this pattern may be broken up, or temporarily interrupted. Thus an essentially "youthful" stream might take on some of the characteristics of a "mature" stream following soil erosion, organic enrichment, and increased surface runoff. Correction of these conditions might likewise be followed by at least a partial reversion to the "original" condition).

C Lakes and Reservoirs

Geological factors which significantly affect the nature of either a stream or lake include the following:

1 The geographical location of the drainage basin or watershed.

2 The size and shape of the drainage basin.

3 The general topography, i.e., mountainous or plains.

4 The character of the bedrocks and soils.

5 The character, amount, annual distribution, and rate of precipitation.

6 The natural vegetative cover of the land is, of course, responsive to and responsible for many of the above factors and is also severely subject to the whims of civilization. This is one of the major factors determining run-off versus soil absorption, etc.

D Lakes have a developmental history which somewhat parallels that of streams. This process is often referred to as natural eutrophication.

1 The methods of formation vary greatly, but all influence the character and subsequent history of the lake.

In glaciated areas, for example, a huge block of ice may have been covered with till. The glacier retreated, the ice melted, and the resulting hole became a lake. Or, the glacier may actually scoop out a hole. Landslides may dam valleys, extinct volcanoes may collapse, etc., etc.

2 Maturing or natural eutrophication of lakes.

a If not already present shoal areas are developed through erosion and deposition of the shore material by wave action and undertow.

b Currents produce bars across bays and thus cut off irregular areas.

c Silt brought in by tributary streams settles out in the quiet lake water

d Algae grow attached to surfaces, and floating free as plankton. Dead organic matter begins to accumulate on the bottom.

e Rooted aquatic plants grow on shoals and bars, and in doing so cut off bays and contribute to the filling of the lake.

f Dissolved carbonates and other materials are precipitated in the deeper portions of the lake in part through the action of plants.

g When filling is well advanced, mats of sphagnum moss may extend outward from the shore. These mats are followed by sedges and grasses which finally convert the lake into a marsh.

3 Extinction of lakes. After lakes reach maturity, their progress toward filling up is accelerated. They become extinct through:

a The downcutting of the outlet.

b Filling with detritus eroded from the shores or brought in by tributary streams.

c Filling by the accumulation of the remains of vegetable materials growing in the lake itself. (Often two or three processes may act concurrently)

III PRODUCTIVITY IN FRESH WATERS

A Fresh waters in general and under natural conditions by definition have a lesser supply of dissolved substances than marine waters, and thus a lesser basic potential for the growth of aquatic organisms. By the same token, they may be said to be more sensitive to the addition of extraneous materials (pollutants, nutrients, etc.) The following notes are directed toward natural geological and other environmental factors as they affect the productivity of fresh waters.

B Factors Affecting Stream Productivity (See Table 1)

TABLE 1

EFFECT OF SUBSTRATE ON STREAM PRODUCTIVITY*

(The productivity of sand bottoms is taken as 1)

Bottom Material	Relative Productivity
Sand	1
Marl	6
Fine Gravel	9
Gravel and silt	14
Coarse gravel	32
Moss on fine gravel	89
Fissidens (moss) on coarse gravel	111
Ranunculus (water buttercup)	194
Watercress	301
Anacharis (waterweed)	452

*Selected from Tarzwell 1937

To be productive of aquatic life, a stream must provide adequate nutrients, light, a suitable temperature, and time for growth to take place.

1 Youthful streams, especially on rock or sand substrates are low in essential nutrients. Temperatures in mountainous regions are usually low, and due to the steep gradient, time for growth is short. Although ample light is available, growth of true plankton is thus greatly limited.

2 As the stream flows toward a more "mature" condition, nutrients tend to accumulate, and gradient diminishes and so time of flow increases, temperature tends to increase, and plankton flourish.

Should a heavy load of inert silt develop on the other hand, the turbidity would reduce the light penetration and consequently the general plankton production would diminish.

3 As the stream approaches base level (old age) and the time available for plankton growth increases, the balance between turbidity, nutrient levels, and temperature and other seasonal conditions, determines the overall productivity.

C Factors Affecting the Productivity of lakes (See Table 2)

1 The size, shape, and depth of the lake basin. Shallow water is more productive than deeper water since more light will reach the bottom to stimulate rooted plant growth. As a corollary, lakes with more shoreline, having more shallow water, are in general more productive. Broad shallow lakes and reservoirs have the greatest production potential (and hence should be avoided for water supplies).

TABLE 2

EFFECT OF SUBSTRATE ON LAKE PRODUCTIVITY *

(The productivity of sand bottoms is taken as 1)

Bottom Material	Relative Productivity
Sand	1
Pebbles	4
Clay	8
Flat rubble	9
Block rubble	11
Shelving rock	77

* Selected from Tarzwell 1937

2 Hard waters are generally more productive than soft waters as there are more plant nutrient minerals available. This is often greatly influenced by the character of the soil and rocks in the watershed and the quality and quantity of ground water entering the lake. In general, pH ranges of 6.8 to 8.2 appear to be most productive.

3 Turbidity reduces productivity as light penetration is reduced.

4 The presence or absence of thermal stratification with its semi-annual turnovers affects productivity by distributing nutrients throughout the water mass.

5 Climate, temperature, prevalence of ice and snow, are also of course important.

D Factors Affecting the Productivity of Reservoirs

1 The productivity of reservoirs is governed by much the same principles as that of lakes, with the difference that the water level is much more under the control of man. Fluctuations in water level can be used to deliberately increase or decrease productivity. This can be demonstrated by a comparison of the TVA reservoirs which practice a summer drawdown with some of those in the west where a winter drawdown is the rule.

2 The level at which water is removed from a reservoir is important to the productivity of the stream below. The hypolimnion may be anaerobic while the epilimnion is aerobic, for example, or the epilimnion is poor in nutrients while the hypolimnion is relatively rich.

3 Reservoir discharges also profoundly affect the DO, temperature, and turbidity in the stream below a dam. Too much fluctuation in flow may permit sections of the stream to dry, or provide inadequate dilution for toxic waste.

IV CULTURAL EUTROPHICATION

A The general processes of natural eutrophication, or natural enrichment and productivity have been briefly outlined above.

B When the activities of man speed up these enrichment processes by introducing unnatural quantities of nutrients (sewage, etc.) the result is often called cultural eutrophication. This term is often extended beyond its original usage to include the enrichment (pollution) of streams, estuaries, and even oceans, as well as lakes.

V CLASSIFICATION OF LAKES AND RESERVOIRS

A The productivity of lakes and impoundments is such a conspicuous feature that it is often used as a convenient means of classification.

1 Oligotrophic lakes are the younger, less productive lakes, which are deep, have clear water, and usually support Salmonoid fishes in their deeper waters.

2 Eutrophic lakes are more mature, more turbid, and richer. They are usually shallower. They are richer in dissolved solids; N, P, and Ca are abundant. Plankton is abundant and there is often a rich bottom fauna.

3 Dystrophic lakes, such as bog lakes, are low in Ph, water yellow to brown, dissolved solids, N, P, and Ca scanty but humic materials abundant, bottom fauna and plankton poor, and fish species are limited.

B Reservoirs may also be classified as storage, and run of the river.

1 Storage reservoirs have a large volume in relation to their inflow.

2 Run of the river reservoirs have a large flow-through in relation to their storage value.

C According to location, lakes and reservoirs may be classified as polar, temperate, or tropical. Differences in climatic and geographic conditions result in differences in their biology.

VI SUMMARY

A A body of water such as a lake, stream, or estuary represents an intricately balanced system in a state of dynamic equilibrium. Modification imposed at one point in the system automatically results in compensatory adjustments at associated points.

B The more thorough our knowledge of the entire system, the better we can judge where to impose control measures to achieve a desired result.

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Descriptors:

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THE AQUATIC ENVIRONMENT

Part 4. The Marine Environment and its Role in the Total Aquatic Environment

I INTRODUCTION

A The marine environment is arbitrarily defined as the water mass extending beyond the continental land masses, including the plants and animals harbored therein. This water mass is large and deep, covering about 70 percent of the earth's surface and being as deep as 7 miles. The salt content averages about 35 parts per thousand. Life extends to all depths.

B The general nature of the water cycle on earth is well known. Because the largest portion of the surface area of the earth is covered with water, roughly 70 percent of the earth's rainfall is on the seas. (Figure 1)

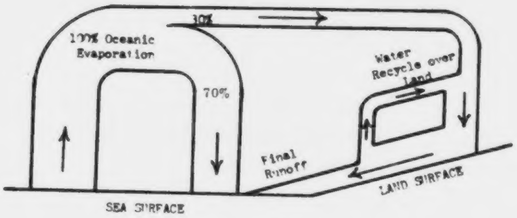

Figure 1. THE WATER CYCLE

Since roughly one third of the rain which falls on the land is again recycled through the atmosphere (see Figure 1 again), the total amount of water washing over the earth's surface is significantly greater than one third of the total world rainfall. It is thus not surprising to note that the rivers which finally empty into the sea carry a disproportionate burden of dissolved and suspended solids picked up from the land. The chemical composition of this burden depends on the composition of the rocks and soils through which the river flows, the proximity of an ocean, the direction of prevailing winds, and other factors. This is the substance of geological erosion. (Table 1)

TABLE 1

PERCENTAGE COMPOSITION OF THE MAJOR IONS OF TWO STREAMS AND SEA WATER

(Data from Clark, F.W., 1924, "The Composition of River and Lake Waters of the United States", U.S. Geol. Surv., Prof. Paper No. 135; Harvey, H.W., 1957, "The Chemistry and Fertility of Sea Waters", Cambridge University Press, Cambridge)

Ion	Delaware River at Lambertville, N.J.	Rio Grande at Laredo, Texas	Sea Water
Na	6.70	14.78	30.4
K	1.46	.85	1.1
Ca	17.49	13.73	1.16
Mg	4.81	3.03	3.7
Cl	4.23	21.65	55.2
SO_4	17.49	30.10	7.7
CO_3	32.95	11.55	*HCO_3 0.35

C For this presentation, the marine environment will be (1) described using an ecological approach, (2) characterized ecologically by comparing it with freshwater and estuarine environments, and (3) considered as a functional ecological system (ecosystem).

II FRESHWATER, ESTUARINE, AND MARINE ENVIRONMENTS

Distinct differences are found in physical, chemical, and biotic factors in going from a freshwater to an oceanic environment. In general, environmental factors are more constant in freshwater (rivers) and oceanic environments than in the highly variable and harsh environments of estuarine and coastal waters. (Figure 2)

A Physical and Chemical Factors

Rivers, estuaries, and oceans are compared in Figure 2 with reference to the relative instability (or variation) of several important parameters. In the oceans, it will be noted, very little change occurs in any parameter. In rivers, while "salinity" (usually referred to as "dissolved solids") and temperature (accepting normal seasonal variations) change little, the other four parameters vary considerably. In estuaries, they all change.

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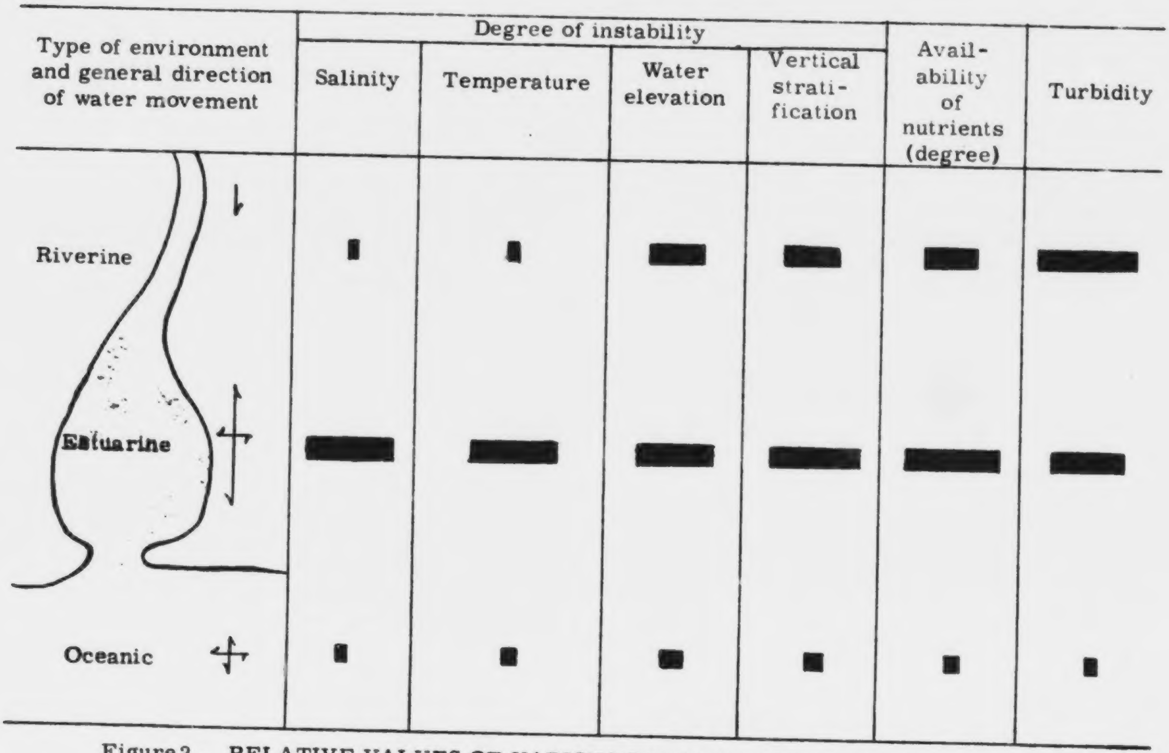

Figure 2. RELATIVE VALUES OF VARIOUS PHYSICAL AND CHEMICAL FACTORS FOR RIVER, ESTUARINE, AND OCEANIC ENVIRONMENTS

B Biotic Factors

1 A complex of physical and chemical factors determine the biotic composition of an environment. In general, the number of species in a rigorous, highly variable environment tends to be less than the number in a more stable environment (Hedgpeth, 1966).

2 The dominant animal species (in terms of total biomass) which occur in estuaries are often transient, spending only a part of their lives in the estuaries. This results in better utilization of a rich environment.

C Zones of the Sea

The nearshore environment is often classified in relation to tide level and water depth. The nearshore and offshore oceanic regions together, are often classified with reference to light penetration and water depth. (Figure 3)

1 Neritic - Relatively shallow-water zone which extends from the high-tide mark to the edge of the continental shelf.

MARINE ECOLOGY

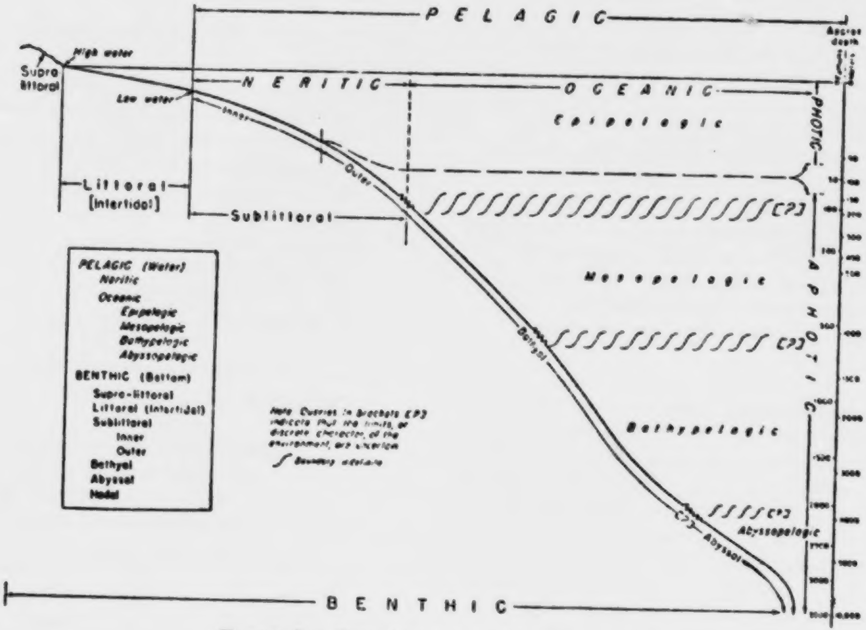
PELAGIC
High water
Supra littoral
Low water
NERITIC
OCEANIC
Inner
Outer
Littoral [Intertidal]
Sublittoral
Epipelagic
PHOTIC
APHOTIC
[?]
Mesopelagic
Bathyal
Bathypelagic
Abyssopelagic
Abyssal
BENTHIC
PELAGIC (Water)
Neritic
Oceanic
Epipelagic
Mesopelagic
Bathypelagic
Abyssopelagic
BENTHIC (Bottom)
Supra-littoral
Littoral (Intertidal)
Sublittoral
Inner
Outer
Bathyal
Abyssal
Hadal

FIGURE 3—*Classification of marine environments*

a Stability of physical factors is intermediate between estuarine and oceanic environments.

b Phytoplankters are the dominant producers but in some locations attached algae are also important as producers.

c The animal consumers are zooplankton, nekton, and benthic forms.

2 Oceanic - The region of the ocean beyond the continental shelf. Divided into three parts, all relatively poorly populated compared to the neritic zone.

a Euphotic zone - Waters into which sunlight penetrates (often to the bottom in the neritic zone). The zone of primary productivity often extends to 600 feet below the surface.

1) Physical factors fluctuate less than in the neritic zone.

2) Producers are the phytoplankton and consumers are the zooplankton and nekton.

b Bathyal zone - From the bottom of the euphotic zone to about 2000 meters.

1) Physical factors relatively constant but light is absent.

2) Producers are absent and consumers are scarce.

c Abyssal zone - All the sea below the bathyal zone.

1) Physical factors more constant than in bathyal zone.

2) Producers absent and consumers even less abundant than in the bathyal zone.

III SEA WATER AND THE BODY FLUIDS

A Sea water is a remarkably suitable environment for living cells, as it contains all of the chemical elements essential to the growth and maintenance of plants and animals. The ratio and often the concentration of the major salts of sea water are strikingly similar in the cytoplasm and body fluids of marine organisms. This similarity is also evident, although modified somewhat in the body fluids of fresh water and terrestrial animals. For example, sterile sea water may be used in emergencies as a substitute for blood plasma in man.

B Since marine organisms have an internal salt content similar to that of their surrounding medium (isotonic condition) osmoregulation poses no problem. On the other hand, fresh water organisms are hypertonic (osmotic pressure of body fluids is higher than that of the surrounding water). Hence, fresh water animals must constantly expend more energy to keep water out (i.e., high osmotic pressure fluids contain more salts, the action being then to dilute this concentration with more water).

1 Generally, marine invertebrates are narrowly poikilosmotic, i.e., the salt concentration of the body fluids changes with that of the external medium. This has special significance in estuarine situations where salt concentrations of the water often vary considerably in short periods of time.

2 Marine bony fish (teleosts) have lower salt content internally than the external environment (hypotonic). In order to prevent dehydration, water is ingested and salts are excreted through special cells in the gills.

IV FACTORS AFFECTING THE DISTRIBUTION OF MARINE AND ESTUARINE ORGANISMS

A Salinity. Salinity is the single most constant and controlling factor in the marine environment, probably followed by temperature. It ranges around 35,000 mg. per liter, or "35 parts per thousand" (symbol: 35‰) in the language of the oceanographer. While variations in the open ocean are relatively small, salinity decreases rapidly as one approaches shore and proceeds through the estuary and up into fresh water with a salinity of "0 ‰ (see Figure 2)

B Salinity and temperature as limiting factors in ecological distribution.

1 Organisms differ in the salinities and temperatures in which they prefer to live, and in the variabilities of these parameters which they can tolerate. These preferences and tolerances often change with successive life history stages, and in turn often dictate where the organisms live: their "distribution."

2 These requirements or preferences often lead to extensive migrations of various species for breeding, feeding, and growing stages. One very important result of this is that an estuarine environment is an absolute necessity for over half of all coastal commercial and sport related species of fishes and invertebrates, for either all or certain portions of their life histories. (Part V, figure 8)

3 The Greek word roots "eury" (meaning wide) and "steno" (meaning narrow) are customarily combined with such words as "haline" for salt, and "thermal" for temperature, to give us "euryhaline" as an adjective to characterize an organism able to tolerate a wide range of salinity, for example; or "stenothermal" meaning one which cannot stand much change in temperature. "Meso-" is a prefix indicating an intermediate capacity.

C Marine, estuarine, and fresh water organisms. (See Figure 4)

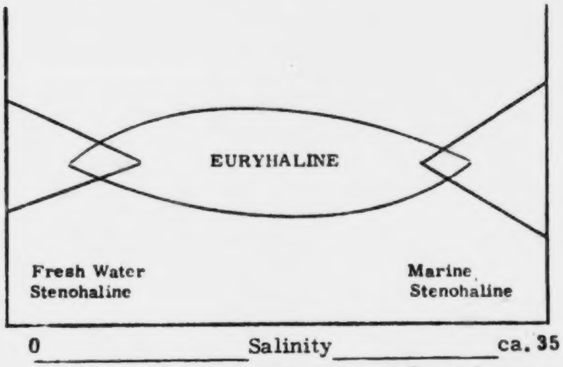

Figure 4. Salinity Tolerance of Organisms

1 Offshore marine organisms are, in general, both stenohaline and stenothermal unless, as noted above, they have certain life history requirements for estuarine conditions.

2 Fresh water organisms are also stenohaline, and (except for seasonal adaptation) meso- or stenothermal. (Figure 2)

3 Indigenous or native estuarine species that normally spend their entire lives in the estuary are relatively few in number. (See Figure 5). They are generally meso- or euryhaline and meso- or eurythermal.

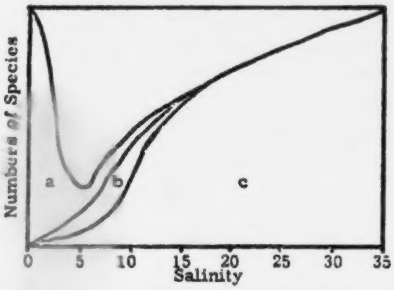

Figure 5. DISTRIBUTION OF ORGANISMS IN AN ESTUARY

a Euryhaline, freshwater
b Indigenous, estuarine, (mesohaline)
c Euryhaline, marine

4 Some well known and interesting examples of migratory species which change their environmental preferences with the life history stage include the shrimp (mentioned above), striped bass, many herrings and relatives, the salmons, and many others. None are more dramatic than the salmon hordes which lay their eggs in freshwater streams, migrate far out to sea to feed and grow, then return to the stream where they hatched to lay their own eggs before dying.

5 Among euryhaline animals landlocked (trapped), populations living in lowered salinities often have a smaller maximum size than individuals of the same species living in more saline waters. For example, the lamprey (Petromyzon marinus) attains a length of 30 - 36" in the sea, while in the Great Lakes the length is 18 - 24".

Usually the larvae of aquatic organisms are more sensitive to changes in salinity than are the adults. This characteristic both limits and dictates the distribution and size of populations.

D The effects of tides on organisms.

1 Tidal fluctuations probably subject the benthic or intertidal populations to the most extreme and rapid variations of environmental stress encountered in any aquatic habitat. Highly specialized communities have developed in this zone, some adapted to the rocky surf zones of the open coast, others to the muddy inlets of protected estuaries. Tidal reaches of fresh water rivers, sandy beaches, coral reefs and mangrove swamps in the tropics; all have their own floras and faunas. All must emerge and flourish when whatever water there is rises and covers or tears at them, all must collapse or retract to endure drying, blazing tropical sun, or freezing arctic ice during the low tide interval. Such a community is depicted in Figure 6.

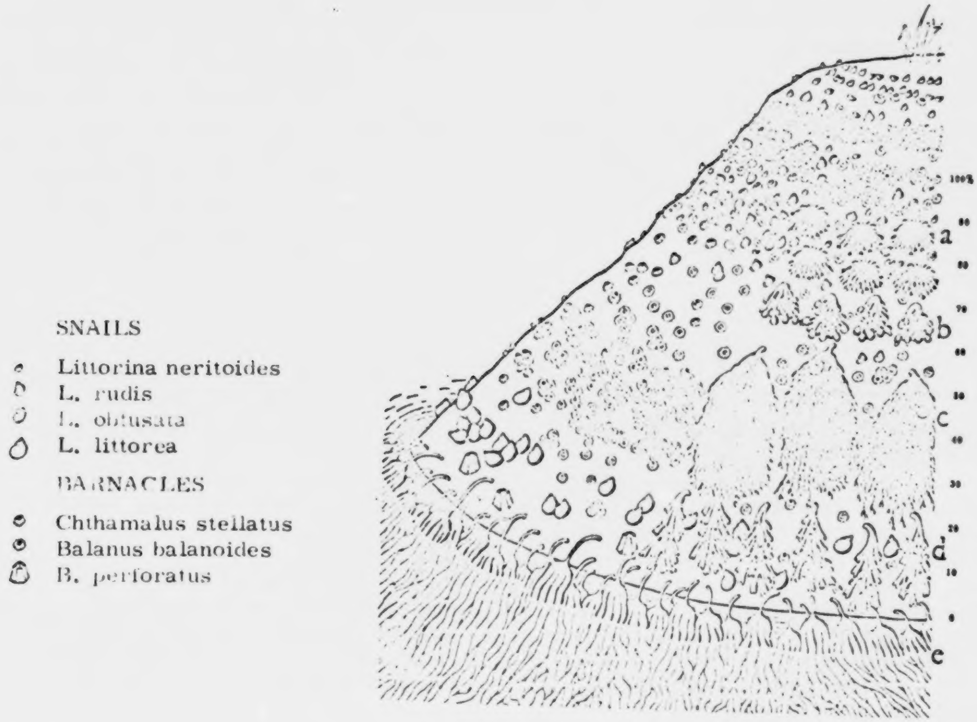
SNAILS
Littorina neritoides
L. rudis
L. obtusata
L. littorea
BARNACLES
Chthamalus stellatus
Balanus balanoides
B. perforatus
100%
90
80
70
60
50
40
30
20
10
0
a
b
c
d
e

Figure 6

Zonation of plants, snails, and barnacles on a rocky shore. While this diagram is based on the situation on the southwest coast of England, the general idea of zonation may be applied to any temperate rocky ocean shore, though the species will differ. The gray zone consists largely of lichens. At the left is the zonation of rocks with exposure too extreme to support algae; at the right, on a less exposed situation, the animals are mostly obscured by the algae. Figures at the right hand margin refer to the percent of time that the zone is exposed to the air, i. e., the time that the tide is out. Three major zones can be recognized: the Littorina zone (above the gray zone); the Balanoid zone (between the gray zone and the laminarias); and the Laminaria zone. a. Pelvetia canaliculata; b. Fucus spiralis; c. Ascophyllum nodosum; d. Fucus serratus; e. Laminaria digitata. (Based on Stephenson)

V FACTORS AFFECTING THE PRODUCTIVITY OF THE MARINE ENVIRONMENT

A The sea is in continuous circulation. Without circulation, nutrients of the ocean would eventually become a part of the bottom and biological production would cease. Generally, in all oceans there exists a warm surface layer which overlies the colder water and forms a two-layer system of persistent stability. Nutrient concentration is usually greatest in the lower zone. Wherever a mixing or disturbance of these two layers occurs biological production is greatest.

B The estuaries are also a mixing zone of enormous importance. Here the fertility washed off the land is mingled with the nutrient capacity of seawater, and many of the would's most productive waters result.

C When man adds his cultural contributions of sewage, fertilizer, silt or toxic waste, it is no wonder that the dynamic equilibrium of the ages is rudely upset, and the environmentalist cries, "See what man hath wrought"!

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THE AQUATIC ENVIRONMENT

Part 5: Wetlands

I INTRODUCTION

A Broadly defined, wetlands are areas which are "to wet to plough but too thick to flow." The soil tends to be saturated with water, salt or fresh, and numerous channels or ponds of shallow or open water are common. Due to ecological features too numerous and variable to list here, they comprise in general a rigorous (highly stressed) habitat, occupied by a small relatively specialized indigenous (native) flora and fauna.

B They are prodigiously productive however, and many constitute an absolutely essential habitat for some portion of the life history of animal forms generally recognized as residents of other habitats (Figure 8). This is particularly true of tidal marshes as mentioned below.

C Wetlands in toto comprise a remarkably large proportion of the earth's surface, and the total organic carbon bound in their mass constitutes an enormous sink of energy.

D Since our main concern here is with the "aquatic" environment, primary emphasis will be directed toward a description of wetlands as the transitional zone between the waters and the land, and how their desecration by human culture spreads degradation in both directions.

II TIDAL MARSHES AND THE ESTUARY

A "There is no other case in nature, save in the coral reefs, where the adjustment of organic relations to physical condition is seen in such a beautiful way as the balance between the growing marshes and the tidal streams by which they are at once nourished and worn away." (Shaler, 1886)

B Estuarine pollution studies are usually devoted to the dynamics of the circulating water, its chemical, physical, and biological parameters, bottom deposits, etc.

C It is easy to overlook the intimate relationships which exist between the bordering marshland, the moving waters, the tidal flats, subtidal deposition, and seston whether of local, oceanic, or riverine origin.

D The tidal marsh (some inland areas also have salt marshes) is generally considered to be the marginal areas of estuaries and coasts in the intertidal zone, which are dominated by emergent vegetation. They generally extend inland to the farthest point reached by the spring tides, where they merge into freshwater swamps and marshes (Figure 1). They may range in width from nonexistent on rocky coasts to many kilometers.

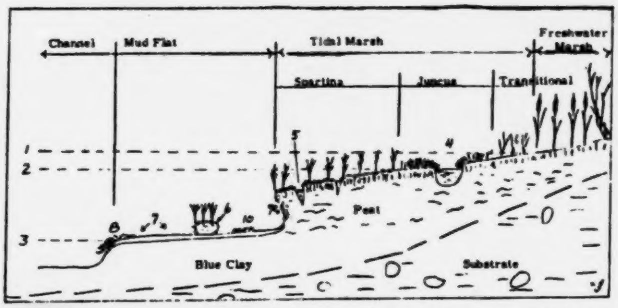

Figure 1. Zonation in a positive New England estuary. 1. Spring tide level, 2. Mean high tide, 3. Mean low tide, 4. Bog hole, 5. Ice cleavage pool, 6. Chunk of *Spartina* turf deposited by ice, 7. Organic ooze with associated community, 8. eelgrass (*Zostera*), 9. Ribbed mussels (modiolus)-clam (*mya*) - mud snail (*Nassa*) community. 10. Sea lettuce (*Ulva*)

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III MARSH ORIGINS AND STRUCTURES

A In general, marsh substrates are high in organic content, relatively low in minerals and trace elements. The upper layers bound together with living roots called turf, underlaid by more compacted peat type material.

1 Rising or eroding coastlines may expose peat from ancient marsh growth to wave action which cuts into the soft peat rapidly (Figure 2). Such banks are likely to be cliff-like, and are often undercut. Chunks of peat are often found lying about on harder substrate below high tide line. If face of cliff is well above high water, overlying vegetation is likely to be typically terrestrial of the area. Marsh type vegetation is probably absent.

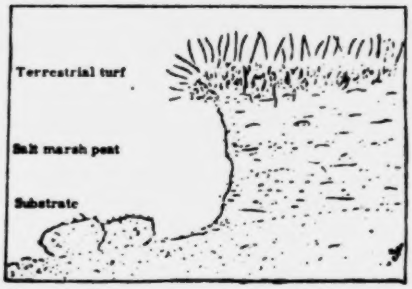

Figure 2. Diagrammatic section of eroding peat cliff

2 Low lying deltaic, or sinking coastlines, or those with low energy wave action are likely to have active marsh formation in progress. Sand dunes are also common in such areas (Figure 3). General coastal configuration is a factor.

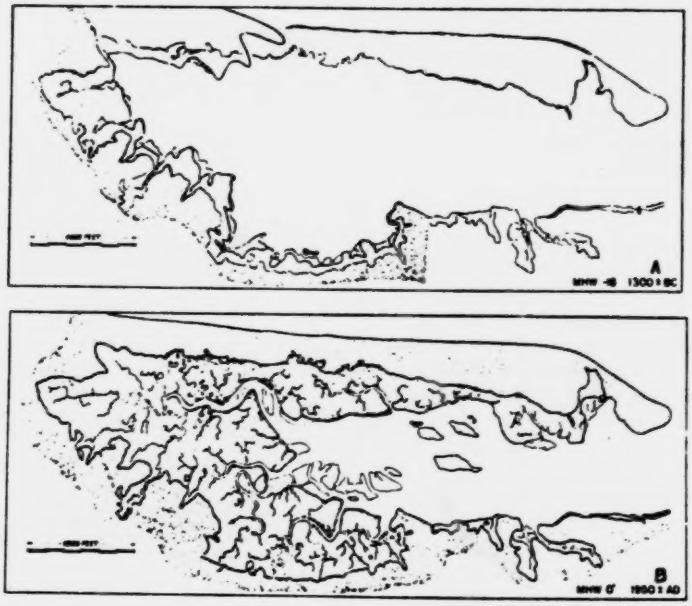

Figure 3

Development of a Massachusetts Marsh since 1300 BC, involving an 18 foot rise in water level. Shaded area indicates sand dunes. Note meandering marsh tidal drainage. A: 1300 BC, B: 1950 AD.

a Rugged or precipitous coasts or slowly rising coasts, typically exhibit narrow shelves, sea cliffs, fjords, massive beaches, and relatively less marsh area (Figure 4). An Alaskan fjord subject to recent catastrophic subsidence and rapid deposition of glacial flour shows evidence of the recent encroachment of saline waters in the presence of recently buried trees and other terrestrial vegetation, exposure of layers of salt marsh peat along the edges of channels, and a poorly compacted young marsh turf developing at the new high water level (Figure 5).

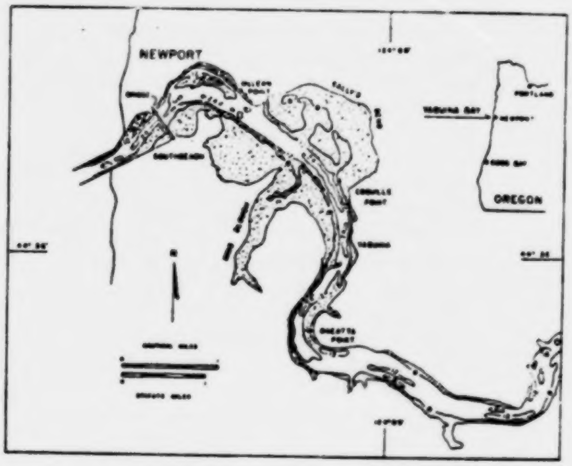

Figure 4 A River Mouth on a Slowly Rising Coast. Note absence of deltaic development and relatively little marshland, although mud flats stippled are extensive.

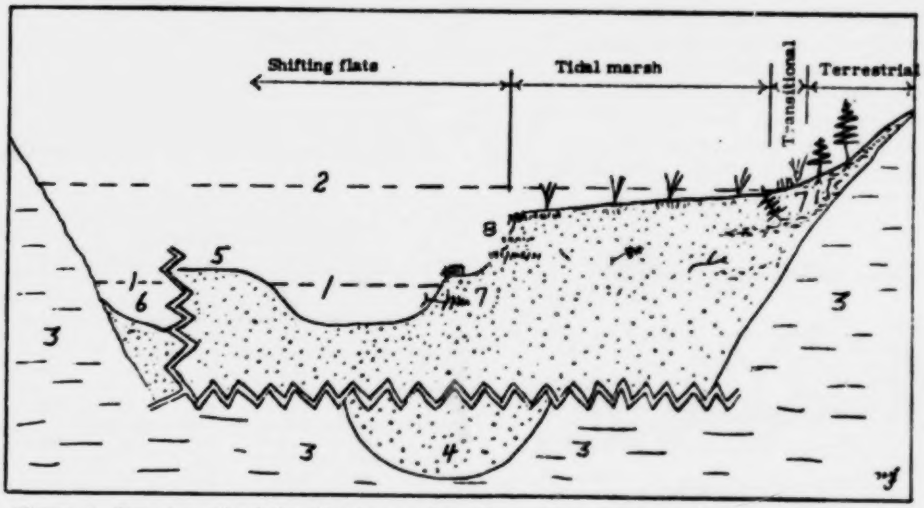

Figure 5 Some general relationships in a northern fjord with a rising water level. 1. mean low water, 2. maximum high tide, 3. Bedrock, 4. Glacial flour to depths in excess of 400 meters, 5. Shifting flats and channels, 6. Channel against bedrock, 7. Buried terrestrial vegetation, 8. Outcroppings of salt marsh peat.

b Low lying coastal plains tend to be fringed by barrier islands, broad estuaries and deltas, and broad associated marshlands (Figure 3).

Deep tidal channels fan out through innumerable branching and often interconnecting rivulets. The intervening grassy plains are essentially at mean high tide level.

c Tropical and subtropical regions such as Florida, the Gulf Coast, and Central America, are frequented by mangrove swamps. This unique type of growth is able to establish itself in shallow water and move out into progressively deeper areas (Figure 6). The strong deeply embedded roots enable the mangrove to resist considerable wave action at times, and the tangle of roots quickly accumulates a deep layer of organic sediment. Mangroves in the south may be considered to be roughly the equivalent of the Spartina marsh grass in the north as a land builder. When fully developed, a mangrove swamp is an impenetrable thicket of roots over the tidal flat affording shelter to an assortment of semi-aquatic organisms such as various molluscs and crustaceans, and providing access from the nearby land to predaceous birds, reptiles, and mammals. Mangroves are not restricted to estuaries, but may develop out into shallow oceanic lagoons, or upstream into relatively fresh waters.

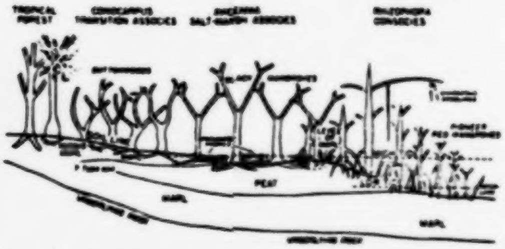

Figure 6 Diagrammatic transect of a mangrove swamp showing transition from marine to terrestrial habitat.

IV PRODUCTIVITY OF WETLANDS

A Measuring the productivity of grasslands is not easy, because today grass is seldom used directly as such by man. It is thus usually expressed as production of meat, milk, or in the case of salt marshes, the total crop of animals that obtain food per unit of area. The primary producer in a tidal marsh is the marsh grass, but very little of it is used by man as grass. (Table 1)

The nutritional analysis of several marsh grasses as compared to dry land hay is shown in Table 2.

TABLE 1. General Orders of Magnitude of Gross Primary Productivity in Terms of Dry Weight of Organic Matter Fixed Annually

Ecosystem	gms/M^2/year (grams/square meters/year)	lbs/acre/year
Land deserts, deep oceans	Tens	Hundreds
Grasslands, forests, eutrophic lakes, ordinary agriculture	Hundreds	Thousands
Estuaries, deltas, coral reefs, intensive agriculture (sugar cane, rice)	Thousands	Ten-thousands

TABLE 2. Analyses of Some Tidal Marsh Grasses

T/A	Percentage Composition					
Dry Wt.	Protein	Fat	Fiber	Water	Ash	N-free Extract
Distichlis spicata (pure stand, dry)						
2.8	5.3	1.7	32.4	8.2	6.7	45.5
Short Spartina alterniflora and Salicornia europaea (in standing water)						
1.2	7.7	2.5	31.1	8.8	12.0	37.7
Spartina alterniflora (tall, pure stand in standing water)						
3.5	7.4	2.0	29.0	8.3	15.5	37.3
Spartina patens (pure stand, dry)						
3.2	6.0	2.2	30.0	8.1	9.0	44.5
Spartina alterniflora and Spartina patens (mixed stand, wet)						
3.4	6.8	1.9	29.8	8.1	10.4	42.8
Spartina alterniflora (short, wet)						
2.2	8.8	2.4	30.4	8.7	13.3	36.3
Comparable Analyses for Hay						
1st cut	6.0	2.0	36.2	6.7	4.2	44.9
2nd cut	11.0	1.7	30.5	10.4	5.9	38.5

Analyses performed by Roland W. Gilbert, Department of Agricultural Chemistry, U.R.I.

B The actual utilization of marsh grass is accomplished primarily by its decomposition and ingestion by micro organisms. (Figure 7) A small quantity of seeds and solids is consumed directly by birds.

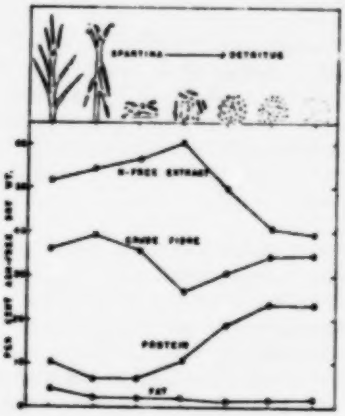

Figure 7 **The nutritive composition of successive stages of decomposition of _Spartina_ marsh grass, showing increase in protein and decrease in carbohydrate with increasing age and decreasing size of detritus particles.**

1 The quantity of micro invertebrates which thrive on this wealth of decaying marsh has not been estimated, nor has the actual production of small indigenous fishes and invertebrates such as the top minnows (Fundulus), or the mud snails (Nassa), and others.

2 Many forms of oceanic life migrate into the estuaries, especially the marsh areas, for important portions of their life histories as is mentioned elsewhere (Figure 8). It has been estimated that in excess of 60% of the marine commercial and sport fisheries are estuarine or marsh dependent in some way.

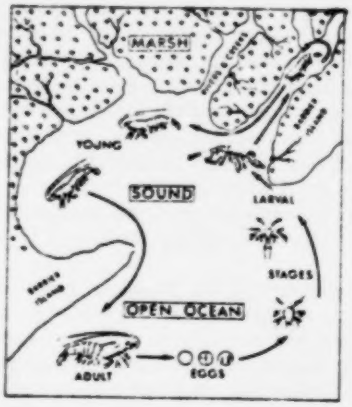

Figure 8 **Diagram of the life cycle of white shrimp (after Anderson and Lunz 1965).**

3 An effort to make an indirect estimate of productivity in a Rhode Island marsh was made on a single August day by recording the numbers and kinds of birds that fed on a relatively small area (Figure 9). Between 700 and 1000 wild birds of 12 species, ranging from 100 least sandpipers to uncountable numbers of seagulls were counted. One food requirement estimate for three-pound poultry in the confined inactivity of a poultry yard is approximately one ounce per pound of bird per day.

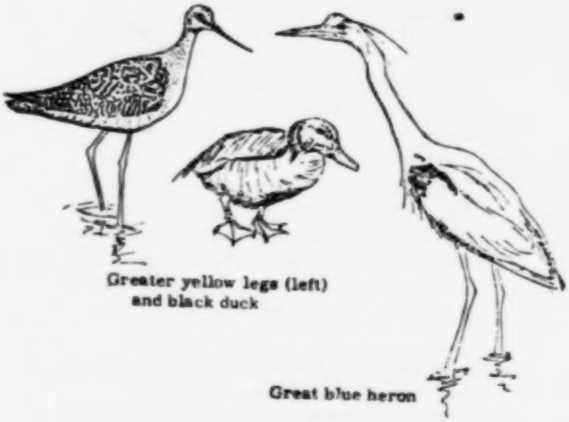

Figure 9 **Some Common Marsh Birds**

One-hundred black bellied plovers at approximately ten ounces each would weigh on the order of sixty pounds. At the same rate of food consumption, this would indicate nearly four pounds of food required for this species alone. The much greater activity of the wild birds would obviously greatly increase their food requirements, as would their relatively smaller size.

Considering the range of foods consumed, the sizes of the birds, and the fact that at certain seasons, thousands of migrating ducks and others pause to feed here, the enormous productivity of such a marsh can be better understood.

V INLAND BOGS AND MARSHES

A Much of what has been said of tidal marshes also applies to inland wetlands. As was mentioned earlier, not all inland swamps are salt-free, any more than all marshes affected by tidal rythms are saline.

B The specificity of specialized floras to particular types of wetlands is perhaps more spectacular in freshwater wetlands than in the marine, where Juncus, Spartina, and Mangroves tend to dominate.

1 Sphagnum, or peat moss, is probably one of the most widespead and abundant wetland plants on earth. Deevey (1958) quotes an estimate that there is probably upwards of 223 billions (dry weight) of tons of peat in the world today, derived during recent geologic time from Sphagnum bogs. Particularly in the northern regions, peat moss tends to overgrow ponds and shallow depressions, eventually forming the vast tundra plains and moores of the north.

2 Long lists of other bog and marsh plants might be cited, each with its own special requirements, topographical, and geographic distribution, etc. Included would be the familiar cattails, spike rushes, cotton grasses, sedges, trefoils, alders, and many, many others.

C Types of inland wetlands.

1 As noted above (Cf: Figure 1) tidal marshes often merge into freshwater marshes and bayous. Deltaic tidal swamps and marshes are often saline in the seaward portion, and fresh in the landward areas.

2 River bottom wetlands differ from those formed from lakes, since wide flood plains subject to periodic inundation are the final stages of the erosion of river valleys, whereas lakes in general tend to be eliminated by the geologic processes of natural eutrophication often involving Sphagnum and peat formation. Riverbottom marshes in the southern United States, with favorable climates, have luxurient growths such as the canebrake of the lower Mississippi, or a characteristic timber growth such as cypress.

3 Although bird life is the most conspicuous animal element in the fauna (Cf: Figure 9), many mammals, such as muskrats, beavers, otters, and others are also marsh-oriented. (Figure 12)

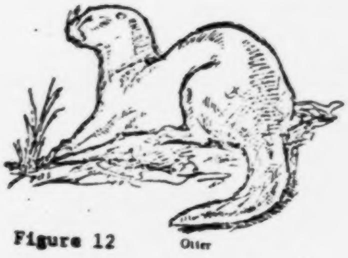

Figure 12 Otter

VI POLLUTION

A No single statement can summarize the effects of pollution on marshlands as distinct from effects noted elsewhere on other habitats.

B Reduction of Primary Productivity

The primary producers in most wetlands are the grasses and peat mosses. Production may be reduced or eliminated by:

1 Changes in the water level brought about by flooding or drainage.

a Marshland areas are sometimes diked and flooded to produce fresh-water ponds. This may be for aesthetic reasons, to suppress the growth of noxious marsh inhabitating insects such as mosquitoes or biting midges, to construct an industrial waste holding pond, a thermal or a sewage stabilization pond, a "convenient" result of highway causeway construction, or other reason. The result is the elimination of an area of marsh. A small compensating border of marsh may or may not develop.

b High tidal marshes were often ditched and drained in former days to stabilize the sod for salt hay or "thatch" harvesting which was highly sought after in colonial days. This inevitably changed the character of the marsh, but it remained as essentially marshland. Conversion to outright agricultural land has been less widespread because of the necessity of diking to exclude the periodic floods or tidal incursions, and carefully timed drainage to eliminate excess precipitation. Mechanical pumping of tidal marshes has not been economical in this country, although the success of the Dutch and others in this regard is well known.

2 Marsh grasses may also be eliminated by smothering as, for example, by deposition of dredge spoils, or the spill or discharge of sewage sludge.

3 Considerable marsh area has been eliminated by industrial construction activity such as wharf and dock construction, oil well construction and operation, and the discharge of toxic brines and other chemicals.

C Consumer production (animal life) has been drastically reduced by the deliberate distribution of pesticides. In some cases, this has been aimed at nearby agricultural lands for economic crop pest control, in other cases the marshes have been sprayed or dusted directly to control noxious insects.

1 The results have been universally disastrous for the marshes, and the benefits to the human community often questionable.

2 Pesticides designed to kill nuisance insects, are also toxic to other arthropods so that in addition to the target species, such forage staples as the various scuds (amphipods), fiddler crabs, and other macroinvertebrates have either been drastically reduced or entirely eliminated in many places. For example, one familiar with fiddler crabs can traverse miles of marsh margins, still riddled with their burrows, without seeing a single live crab.

3 DDT and related compounds have been "eaten up the food chain" (biological magnification effect) until fish eating and other predatory birds such as herons and egrets (Figure 9), have been virtually eliminated from vast areas, and the accumulation of DDT in man himself is only too well known.

D Most serious of the marsh enemies is man himself. In his quest for "lebensraum" near the water, he has all but killed the water he strives to approach. Thus up to twenty percent of the marsh--estuarine area in various parts of the country has already been utterly destroyed by cut and fill real estate developments (Figures 10, 11).

E Swimming birds such as ducks, loons, cormorants, pelicans, and many others are severely jeopardized by floating pollutants such as oil.

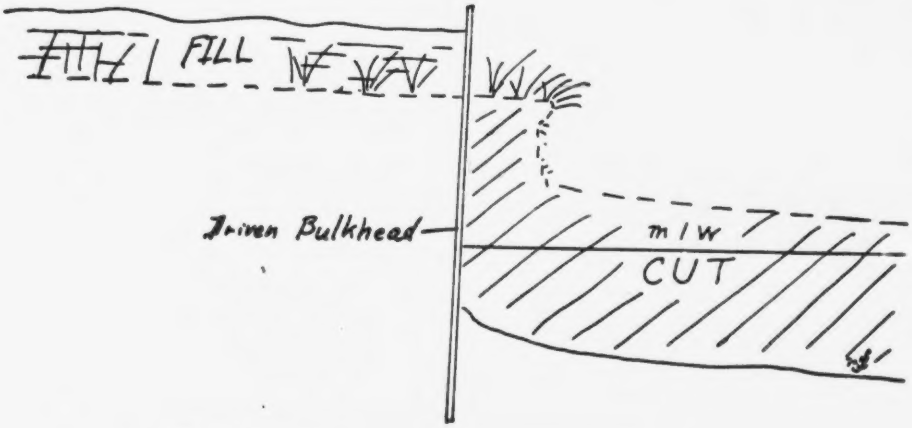
FILL
Driven Bulkhead
mlw
CUT

Figure 10. Diagrammatic representation of cut-and-fill for real estate development. mlw = mean low water

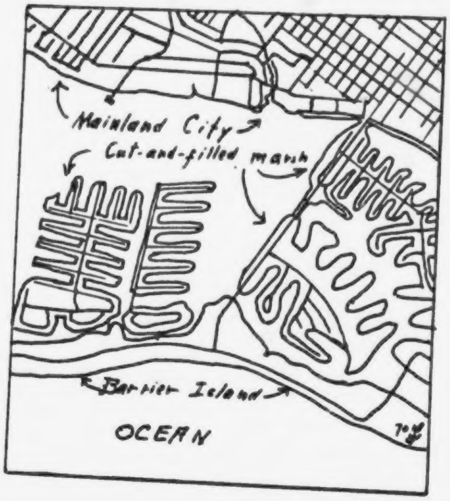
Mainland City
Cut-and-filled marsh
Barrier Island
OCEAN

Figure 11. Tracing of portion of map of a southern city showing extent of cut-and-fill real estate development.

VII SUMMARY

A Wetlands comprise the marshes, swamps, bogs, and tundra areas of the world. They are essential to the well-being of our surface waters and ground waters. They are essential to aquatic life of all types living in the open waters. They are essential as habitat for all forms of wildlife.

B The tidal marsh is the area of emergent vegetation bordering the ocean or an estuary.

C Marshes are highly productive areas, essential to the maintenance of a well rounded community of aquatic life.

D Wetlands may be destroyed by:

1 Degradation of the life forms of which it is composed in the name of nuisance control.

2 Physical destruction by cut-and-fill to create more land area.

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Descriptors: Aquatic Environment, Estuarine Environment, Lentic Environment Lotic Environment, Currents, Marshes, Limnology

TYPES OF ALGAE

I INTRODUCTION

A Algae in general may be defined as small pigmented plant-like organisms of relatively simple structure. Actually the size range is extreme: from only a few microns to over three hundred feet in length. Commonly observed examples include the greenish pond scum or frog spittle of freshwater ponds, much of the golden brown slime covering rocks in a trout stream, and the great marine kelps and seaweeds. Large freshwater forms as Nitella and Chara or stonewort are also included.

B Algae approach ubiquity in distribution. In addition to the commonly observed bodies of water, certain algae also live in such unlikely places as thermal springs, the surface of melting snow, on the hair of the three toed sloth in Central America, and in conjunction with certain fungi to form lichens.

II ALGAE WILL BE GROUPED FOR THE SAKE OF CONVENIENCE INTO FOUR GENERAL TYPES:

A Blue-greens (See plate: Blue-Green Algae, Cyanophyceae). This is a valid technical group. The size range is not very great, some being so small as to approach the size range of the bacteria.

1 These are the only algae in which the pigments are not localized in definite bodies but dissolved throughout the cell. Blue, red, or other pigments are present in addition to chlorophyll thus giving the cells a bluish green, yellow, or red color, at least enmasse.

2 The nucleus lacks a nuclear membrane.

3 Tend to achieve nuisance concentrations more frequently in the warm summer months and in the richer waters.

4 Vegetative reproduction, in addition to cell division, includes the formation of "hormogones," or short specifically delimited sections of trichomes (filaments).

5 Spores of three types are encountered:

a Akinetes are usually larger, thick-walled resting spores.

b Heterocysts appear like empty cell walls, but are actually filled with protoplasm, have occasionally been observed to germinate.

c Endospores, also called "gonidia" or conidia, are formed by repeated division of the protoplast within a given cell wall. Present in only a few genera.

6 Some common examples of blue green algae are:

Anacystis (Microcystis or Polycystis), Anabaena, Aphanizomenon, and Oscillatoria,

B The Pigmented flagellates (in contrast to the non-pigmented or animal-like flagellates) are a heterogeneous collection of motile forms from several different algal groups (See plate: Flagellated algae).

1 There may be one, two, four, or more flagella per cell.

2 There is a well organized nucleus.

3 A light-sensitive red eyespot usually present.

4 The chlorophyll is contained in one or more distinctive bodies called plastids.

5 Two or more cells may be associated in a colony.

6 Non-motile life history stages may be encountered.

7 Masses of stored starch called pyrenoid bodies are often conspicuous.

8 Some examples of pigmented flagellates are: Euglena, Phacus, Chlamydomonas, Gonium, Volvox, Peridinium, Ceratium Mallomonas, Synura and Dinobryon.

C The Non-motile green algae constitute another heterogeneous assembly of unrelated forms (See plate: Non-Motile Green Algae)

1 Like the flagellates they have well organized nuclei and chloroplasts. The shape of the chloroplast is often distinctive.

2 They lack flagella or any other locomotor device.

3 There is extreme structural variation among the group.

4 Some types tend to occur as a general planktonic mass or "bloom," often in combinations of two or more species.

Some examples are: Sphaerocystis, Pediastrum, Scenedesmus, and the desmid Cosmarium.

5 Threadlike (filamentous) green algae may form masses or blankets, cutting off light, and reducing water circulation. They also add considerably to the total mass of organic matter. Some examples of this type are: Spirogyra, Hydrodictyon, Cladophora, Oedogonium, and Chara.

D The Diatoms constitute another valid technical group (See plate: Diatoms-Bacillariophyceae).

1 In appearance, they are geometrically regular in shape. The presence of a brownish pigment in addition to the chlorophyll gives them a golden to greenish color.

2 Motile forms have a distinctive hesitating progression.

3 The most distinctive structural feature is the two-part shell (frustule) composed of silicon dioxide (glass).

a One part fits inside the other as the two halves of a pill box, or a petri dish.

b The surface of these shells are sculptured with minute pits and lines arranged with geometrical perfection.

c The view from the side is called the "girdle view," that from above or below, the "valve view."

4 There are two general shapes of diatoms, circular (centric) and elongate (pennate). The elongate forms may be motile, the circular ones are not.

5 Diatoms may associate in colonies in various ways.

6 Examples of diatoms frequently encountered are: Stephanodiscus Cyclotella, Asterionella, Fragilaria, Tabellaria, Synedra, and Nitzschia.

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KEY FOR IDENTIFICATION OF GROUPS OF FRESHWATER ALGAE

Beginning with "1a" and "1b", choose one of the two contrasting statements and follow this procedure with the "a" and "b" statements of the number given at the end of the chosen statement. Continue until the name of the algal group is given instead of another key number.

1a. Plastid (separate color body) absent; complete protoplast pigmented; generally blue-green; iodine starch test* negative -------------------------------- Blue-green algae

1b. Plastid or plastids present; parts of protoplast free of some or all pigments; generally green, brown, red, etc., but not blue-green; iodine starch test* positive or negative-------- 2

2a. Cell wall permanently rigid (never showing evidence of collapse), and with regular pattern of fine markings (striations, etc.); plastids brown to green; iodine starch test* negative; flagella absent; wall of two essentially similar halves, one placed over the other as a cover-----------------Diatoms

2b. Cell wall, if present, capable of sagging, wrinkling, bulging or rigidity, depending on existing turgor pressure of cell protoplast; regular pattern of fine markings on wall generally absent; plastids green, red, brown, etc.; iodine starch test* positive or negative; flagella present or absent; cell wall continuous and generally not of two parts----------------- 3

3a. Cell or colony motile; flagella present (often not readily visible); anterior and posterior ends of cell different from one another in contents and often in shape-------------------Flagellate algae

3b. Non-motile; true flagella absent; ends of cells often not differentiated-------------------Green algae and associated forms

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*Add one drop Lugol's (iodine) solution, diluted 1-1 with distilled water. In about 1 minute, if positive, starch is stained blue and, later black. Other structures (such as nucleus, plastids, cell wall) may also stain, but turn brown to yellow.

CMP

COMPARISON OF FOUR MAJOR GROUPS OF ALGAE

	Blue-Green	Pigmented flagellates	Greens	Diatoms
Color	Blue-Green (Brown)	Green Brown	Green	Brown (Light-Green)
Location of pigment	Throughout cell	In plastids	In plastids	In plastids
Starch	Absent	Present or Absent	Present	Absent
Slimy coating	Present	Absent in most	Absent in most	Absent in most
Nucleus	Absent	Present	Present	Present
Flagellum	Absent	Present	Absent	Absent
Cell Wall	Inseparable from slimy coating	Thin or Absent	Semi-rigid smooth or with spines	Very rigid, with regular markings
"Eye" spot	Absent	Present	Absent	Absent

Name ________________________________

Production of Excess Organic Material in Freshwater

1. What is it?

2. Through sensory perception characterize at least five things about it which could be significant?

   a.

   b.

   c.

   d.

   e.

3. If present in excessive amounts in water courses or water bodies, what would be its significance?

   a.

   b.

   c.

4. How do you account for the contrast in color of the two samples?

5. This alga using the key below is ____________________.
(Circle the correct number in each pair as you make a choice between the two)

The following key is designed to aid in the recognition of algae in their natural habitats. The decisions to be made will depend upon the features of the habitats and upon the gross structure of the algae. A hand lens may be helpful but it is not essential.

The key includes only those algae which are macroscopic and with a definite organization, or those which have distinguishing features because of numbers present. The users judgement precludes the necessity for minutely describing each habitat.

FIELD KEY TO SOME GENERA OF ALGAE

1. Living in or upon animals	2
1. Not living in such association with animals	6
2. On shells of snapping turtles (also on *Viviparus malleatus* Reeve in L. Erie); filamentous, tufted, coarse	Basicladia
2. Not on turtle shells	3
3. Forming a hard green coating on snail shells	Gongrosira
3. Not on snail shells	4
4. Green masses attached to anterior and posterior appendanges of fairy shrimp or to copepods	Characium
4. Not attached to fairy shrimp or copepods	5
5. In old egg masses of the salamander *Ambystoma*; dark green	Oophila
5. Living within green *Hydra* or green planaria	Chlorella (Zoochlorella)
6. Aquatic, submerged or nearly so	15
6. Not aquatic; on soil, rock, concrete, wood, or bark	7
7. On soil, rock, or concrete	9
7. On wood or bark	8
8. On shaded side of tree trunks, or on weathered siding of old buildings	Protococcus
8. On rotting logs or pilings, pale green	Hormidium Stichococcus
9. On rock or concrete	10
9. On soil	11
10. Algal mass orange or reddish; on "dry" cliff or quarry faces	Trentepohlia
10. Algal mass dark olive to black; slimy (peeling if dry)	Oscillatoria
11. Algal mass filamentous; often in greenhouses	12
11. Algal mass not filamentous or felt-like; locations various	14
12. Dark green; felt-like, coarsely branched	Vaucheria
12. Yellow green, tawny or olive-brown	13
13. Yellow green; filmy	Hormidium
13. Tawny or olive brown; velvet or felt-like	Scytonema
14. Algal mass jelly-like, spherical or in expanded sheets	Nostoc
14. Algal mass globular, 1-2mm in diameter; shining, with white flakes	Botrydium
15. Running water, lake shores, or in spray; attached	16
15. Standing or very slow moving water; attached or not	34
16. Water cold; late winter, early spring, or spring fed	17
16. Water cool to warm; late spring, summer, autumn	27
17. Algal mass filamentous	18
17. Algal mass not filamentous	24
18. Algal mass a felt-like mat	Vaucheria
18. Algal mass not a felt-like mat	19
19. Plants not branched	20
19. Plants profusely branched (bushy)	21
20. Plants short; slippery; bright green	Ulothrix
20. Plants noduiose; cartilagenous; olive	Lemanea
21. Plants embedded in a jelly-like mass	22
21. Plants not gelatinous, "dry," coarse; often in very swift water	Cladophora
22. Olive-green to red-purple	Batrachospermum
22. Brilliant green	23
23. Gelatinous mass soft, indefinite, lateral branches long	Stigeoclonium
23. Gelatinous mass firm, definite, lateral branches short and mostly at right angles to main axis	Draparnaldia
24. Colony brown, gelatinous, amorphous, spreading over rocks	Diatoms
24. Colony green, gelatinous, not amorphous	25
25. Colony tubular, convolute, "like green intestines"	Enteromorpha
25. Colony saccate, membranaceous, or if tubular, not convolute	26
26. Colony firm, easily handled intact	Monostroma
26. Colony delicate, readily disintegrating when handled	Tetraspora
27. Filamentous, branched or not branched	28
27. Algal mass not filamentous	32
28. Filaments branched	29
28. Filaments not branched	31
29. Algal mass a felt-like mat	Vaucheria
29. Algal mass not felt-like, in turbulent water	30
30. Algal mass bushy, coarse, dark green	Cladophora
30. Algal mass slimy, bright green	Stigeoclonium
31. Filaments short (to 1 inch), noduiose, dark olive; in turbulent water	Lemanea
31. Filaments long (to 2 feet), silky, green; mass tough	Rhizoclonium
32. Colonies "shot-like," olive to black; on rock	Nostoc
32. Colonies not "shot-like," some shade of green	33
33. Green incrustation on rocks and sticks; calcareous	Chlorotylium
33. Colonies green, gelatinous pads or sacs	Tetraspora
34. Cold water; late winter or early spring	35
34. Cool to warm water; late spring, summer, autumn	40
35. Woodland pools, leaf litter bottom	36
35. Open ponds, lake margins, pools, "cut-offs"	37
36. Algal mass yellow-green, filamentous, silky	Tribonema
36. Green, motile spheres visible in a glass jar of the water	Volvox
37. Plants tree-like, often calcareous, attached to bottom	Chara Nitella
37. Filamentous	38
38. Attached to dead or living sticks, weeds and grass	Oedogonium
38. Free floating	39
39. Brilliant green, slippery; ends of mass curling when held aloft	Spirogyra
39. Bright to light green, less slippery; ends of mass not distinctly curling	Zygnema Mougeotia
40. Temporary bodies of water	41
40. Permanent or semipermanent bodies of water	44
41. Bird baths, urns, limestone shoreline depressions; reddish scum on bottom and sides	Sphaerocystis (Haematococcus)
41. Puddles, cow tracks, ruts, manure water pools	42
42. Blue-green, olive, black; slimy, membranareous, often on mud	Oscillatoria
42. Green or red; living in or on the water	43
43. Forming a red or green scum on the surface of the water	Euglena
43. Water uniformly green throughout	Chlamydomonas Pandorina Eudorina
44. Aquaria, bottles and culture dishes in laboratory or greenhouse	45
44. Ponds, lakes, lake margins, "cut-offs"	46
45. As a green film on the glass walls	Chlorella
45. Water uniformly green throughout	Scenedesmus Ankistrodesmus
46. On wet soil at margins	47
46. Aquatic, floating or submerged	48
47. Globular, gelatinous colonies	Nostoc
47. Slimy, membranaceous colonies, blue-green, olive, black	Oscillatoria
48. Submerged and attached	49
48. Free floating, or enmeshed in other aquatics	53
49. Plants tree-like; often calcareous; growing on bottom mud, scarcely submerged to 30 feet	Chara Nitella
49. Plants not tree-like; not calcareous	50
50. Filamentous	51
50. Not filamentous	52
51. Filaments dichotomously branched; growing on bottom mud	Dichotomosiphon
51. Filaments not branched; attached to sticks, weed and grass stems	Oedogonium
52. Small hemispherical or branched gelatinous colonies; green; attached to weeds, sticks, or stones	Chaetophora
52. Flat green discs, often attached to dead cattail or water lily leaves	Coleochaete
53. Algal mass forming a net	Hydrodictyon
53. Algal mass not net-like	54
54. Algal mass a tough, membranareous, paper-like sheet; green to olive-green	Lyngbya
54. Algal mass not a membranaceous sheet	55
55. Algal mass filamentous; green	59
55. Algal mass not filamentous	56
56. Green motile spheres visible in a glass jar of the water	Volvox
56. Algal mass nonmotile, definitely macroscopic	57
57. Algal mass irregular, gelatinous lumps; yellow to tawny	Gloeotrichia
57. Algal particles blue-green; dispersed throughout the water, or floating as a bluish scum; sticky in mass	58
58. Particles appearing as "chopped grass" in the water	Aphanizomenon
58. Particles of irregular shape and size	Anabaena Anacystis (Microcystis)
59. Filaments coarse, branched, not slippery	60
59. Filaments silky, unbranched, slippery	61
60. Filaments with well defined, scattered, dark, swollen areas	Pithophora
60. Filaments without dark, swollen areas	Cladophora
61. Bright green to yellowish, very slippery if green; ends of mass curling if held aloft	Spirogyra
61. Green to yellowish, only slightly slippery; ends of mass not curling	Zygnema Mougeotia

6. Classification of this alga is:

Kingdom ____________________
Phylum ____________________
Class ____________________
Order ____________________
Family ____________________
Genus ____________________
Species ____________________

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AQUATIC MACROPHYTES

I INTRODUCTION

A This non-taxonomic description of aquatic plants includes not only the higher vascular plants, but also the larger algae like Chara and Lemanea and the mosses and liverworts. Many manuals on higher aquatic plants will also include the larger algae and lower plants for ecological convenience.

B Ecologically they are primary producers as are the phytoplankton. Their role in detrital cycles is considerable.

C The littoral zone of lakes and estuaries are often dominated by this group while in streams they fill important niches in both the riffles and shallow pool areas.

Water depth determines the adjustment of aquatic seed plants into three principal categories.

1 Surface or floating weeds generally grow in deeper water at the front of (oftentimes commingling with) the emersed weeds. The larger floating weeds are waterlilies that may be rooted in the mud of the bottom and bear large leaves that float upon the surface. Smaller types such as the duckweeds are free-floating.

2 Emersed weeds are those that occupy shallow water, are rooted in bottom mud, and support foliage, seeds and mature fruit one or more feet above the water surface. Cattails, rushes, and the marsh grasses are familiar examples.

3 Submersed aquatic growths often form a belt or zone of herbage farthest from shore. Except for those forms that dwell in quiet waters, they are rooted to the bottom. Depth varies considerably within this zone and may extend down to the limits of effective light penetration.

D In the long-term cycle of the change in the aquatic terrain there is a continuing tendency for the land to encroach upon shallow ponds and shallow areas of lakes, decrease their size, make them more shallow and eventually return them to dry land. Rooted and other aquatic vegetation plays a prominent role in this gradual process by:

1 Invading shallow water areas through entrapment of particulate matter that is carried into lakes and ponds. The rooted vegetation will continue to spread as water areas become more shallow and the bottom mud provides suitable anchorage for roots. Mangrove growths in estuaries and along seashore areas have made swamps out of once open water areas.

2 Plants contribute also to the filling in of lakes and estuaries through both the precipitation of calcium carbonate and the accumulation of their remains upon death and decay; e.g., marl and peat moss.

E While these lake invasions by higher aquatic plants may sometimes be sufficiently rapid to be recognized by those who habitually use the lake, the common objections to rooted vegetation stem from their immediate interference with recreational use such as boating and encroachment on navigation channels and swimming beaches.

II MACROPHYTE GROUPS

A Division Algae

The green alga Chara (and related genera Nitella and Tolypella) may form "weed beds" (in lakes, ponds, streams, and estuaries) as extensive as higher plants and grossly similar. Other algae such as Lemanea may form dense mats in riffle areas of streams or springs. In marine waters the larger marine algae may form dense mats.

B Division Bryophyta (Liverworts and Mosses)

These are relatively small plants which lack flowers and conducting tissues (xylem and phloem).

1 The Life Cycle consists of two phases:

a The leafy green gametophyte which produces motile gametes.

b The sporophyte generation producing spores.

2 This is a freshwater group consisting of less than 50 genera. About one fourth of these are liverworts.

a The liverworts (Class Hepaticae) are small flattened green plants which may lack stems and leaves. Riccia is a slender, branched surface form growing in loose clusters of flat slender sprays. Fragments of these are often taken in plankton samples. Ricciocarpus is a notched oval form about one centimeter in diameter that is often found in the same environment.

b The true mosses (Class Musci) have distinct leaves and stems. Sphagnum forms extensive bogs in some areas. In cooler streams Fontinalis may occupy large areas. One species of the latter has been found resistant to a variety of complex wastes, including zinc.

c In swamps and along lake shores many species pass from an aquatic to terrestrial environment without showing specific morphological changes.

C Vascular Plants (Division Tracheophyta) include the aquatic fern or fern-like plants (Class Pteridophyta).

1 The aquatic lower tracheophytes are primarily freshwater. The Quillworts (Isoetaceae) are related to the club mosses and may form numerous rosettes on the silt-sand bottoms of lakes.

Division Tracheophyta - This division, like the preceding one (Bryophyta) has the life cycle of alternation of gametophyte and sporophyte. In this group, however, the sporophytes always become free living, independent plants with possession of conducting or vascular tissues (xylem and phloem). The aquatic lower Tracheophyta are primarily freshwater and only represented by a few species.

2 Included in the higher Tracheophyta are ferns (Class Filicinae) containing aquatic genera, Azolla, Salvinia, Marsilea, Ceratopteris.

a Azolla and Salvinia form floating masses sometimes interspersed with Duckweed. The former often forms a red carpet.

b Marsilea occupies the area between high and low water of stream and bayou margins.

c Ceratopteris is a floating form often of nuisance locally.

D Vascular Plants (Division Tracheophyta, Class Angiospermae)

1 Structural modification - all aquatic plants are characterized by certain specific morphological features relative to adaptation for the aquatic habitat.

a Many heterophyllous - submerged leaves may be narrow or incised. Surface leaves have simple compact blades.

b Root system only an anchor, with adsorption of dissolved salts taking place over entire plant surface, lacking root hairs.

c Stomata present only on upper side of leaves in floating plants.

d Chloroplasts located in the epidermis.

e Flower clusters may be above water and pollinated by wind or insects or pollen suspended in the water and pistils pollinated under water.

f Vegetative reproduction predominates. Small fragments (turions or winter buds) or root stocks (tubers) may be sufficient for propagation.

g A variety of plants are associated with the aquatic environment making a clear distinction between terrestrial and true hydrophytes difficult. Aquatic plants have been defined by Reid as "those whose seeds germinate in either the water phase or the substrate...and must spend part of their life cycle in water." This, therefore, includes submersed as well as emersed.

2 Classification - Around fifty families of Angiosperms are primarily aquatic, including thirty estuarine species.

3 Dicotyledons

a Family Nymphaceae - the water lilies, Nuphar and Nymphaea Watershield, Brasenia; and Cabomba.

b Family Ceratophyllaceae - includes one genera Ceratophyllum (Coontail or Hornwort). The stems which are entirely under water may sometimes be stiff with a coat of lime.

c Family Trapaceae - the water chestnut or caltrop, Trapa. The sharp spined fruits are a staple crop in parts of Asia. Colonies of connected rosettes of this plant quickly form surface floating mats which may impede navigation in the littoral region of lakes and in slow-moving rivers. Examples - Africa, Rumania, and Massachusetts.

d Family Haloragidaceae - includes two genera Proserpinica and Myriophyllum. The latter is found up to 15 parts per 1000 salinity and has been a serious nuisance in Chesapeake Bay and the Tennessee Valley. In the former area, a virus has reduced populations as much as 95 percent.

e Podostemaceae - primarily a tropical family which is highly adapted to life in rushing water, even in torrential areas over rocks worn smooth by the water and impenetrable by roots. This is made possible by haptera (attachment organs) which cement the plant to the substrate. Morphologically and ecologically they bear resemblances to certain attached algae. This group also shares the characteristics of other aquatic plants, but in addition possesses quantities of silica in the cell. Where the current in the stream is less vigorous the Podostemum will be replaced by mosses and algae. Podostemum communities are a challenge in quantitative sampling of the associated macroinvertebrates.

f Family Lentibulariaceae - Bladderworts, Utricularia, have small bladders which keep the stems afloat and also serve as traps for the capture of small organisms.

g Family Rhizophoraceae - Rhizophora mangle. The red mangrove.

h Family Combretaceae - Combretaceae - Laguncularia racemosa. The white mangrove.

i Family Verbenaceae - Avincennia nitida. The black mangrove
The three mangrove families listed above are widespread on both the East and West Coasts. They support a unique algal vegetation, mainly of certain red algal genera.

4 Monocotyledons

a Family Butomaceae - Butomus umbellatus is Eurasian in origin, and has spread rapidly in the St. Lawrence River Basin and around the Great Lakes.

b Family Hydrocharitaceae - includes the well known Elodea (=Anacharis) Hydrilla, Egeria, and Vallisneria plus two marine genera Halophila and Thalassia (T. testudinum, Turtle Grass.) The former fresh water genera also extend into brackish water.

c The water plantain family (Alismaceae) is a large group of emersed marsh plants and submersed aquatics. Sagittaria subulata is found in both fresh and estuarine areas. In the latter it matures without much change in shape or size of leaves (ribbon leaf form) and the plant and flowers may be under water at high tide.

d Family Zosteraceae

1) Zostera marina or Eel Grass is found on both coasts from Alaska to California and Hudson Bay to North Carolina. In the early thirties, there were great mortalities of Eel Grass over extensive areas, particularly the East Coast. Since that time there has been considerable recovery in the east.

2) Phyllospadix scouleri or Surf Grass is found from British Columbia to California. The "sea grasses" include the above four genera and two others (discussed in the families Hydrocharitaceae and Zannichelliaceae. They are stenohaline and probably do not occur where salinities are below 25 ‰ for considerable periods. The remaining genera of this family are primarily fresh water although many have species extending into brackish water.

e Family Potamogetonaceae

Potamogeton includes over forty species and is recognized generally as a difficult group to key out.

f Family Ruppiaceae

Ruppia maritima or Widgeon Grass is found from alkali to fresh water and salt to fresh coastal water.

g Family Zannichelliaceae

1) Zannichellia palustris is found from fresh water and fresh to brackish coastal water.

2) Cymodoceae - Syringodium filiforme (= Cymodocea manatorum) or Manatee Grass is found from Texas to Florida. The leaves are round in cross-section and flowers are common.

3) Halodule wrightii (= Diplanthera) or Shoal Grass is found in North Carolina and from Texas to Florida. Leaves are flat in cross-section and have a three pointed tip.

h Family Najadaceae - includes the one genus Najas, approximately 35 species. Southern Naiad has long been one of the most troublesome submersed aquatic weeds in Florida. It infests irrigation and drainage canals.

i Family Pontederiaceae - includes Eichornia crassipes, waterhyacinth. It is a native of tropical America and was probably introduced in the United States as an ornamental. As an escapee it has become an exceedingly troublesome species by clogging waterways of the Southern States. Its attractive blue-purple flowers and characteristic bulbous leaf stem with rounded leaf blade make it easy to identify. The plant is usually found floating on the surface of ponds and quiet streams and growing on mudbanks. This plant spreads vegetatively by horizontal stem growth and rooting at the nodes to produce new plants that develop into mats covering large areas. The capsulelike fruits contain many seeds that provide for extensive spread of the species in suitable climates.

j Family Acanthaceae - Dianthera (= Justicia) or Water Willow forms large beds at the margins of streams.

k Marsh and shore zones are inhabited by Bulrushes or Sedges (Family Cyperaceae), Rushes (Family Juncaceae), and Grasses (Gramineae). The latter includes wild rice (Zizania)and Cord Grass (Spartina).

l Family Amaranthaceae - includes Alternanthera philoxeroides or Alligator Weed.

m Family Lemnaceae - The Duck weed family includes the smallest known flowering plants, all of which are free floating. Wolffia and Wolffiella are without roots and Lemna and Spirodela both possess them.

n Family Typhaceae - one genus Typha. Cattail or tule.

o Family Iridaceae - Iris pseudacoris is another European plant becoming widely established in North America.

p Family Araceae - Acorus calamus, sweet flag, is an Eurasian plant which has become widely established in North America.

III TYPICAL AQUATIC PLANT COMMUNITIES

A Ponds and lakes not only have a characteristic plant zonation, but over a period of years exhibit a distinct succession of aquatic plant communities.

B Intertidal salt marshes are so distinctive that in one state,regulations preventing the disruption of the ecology of salt marshes, are defined on the basis of the specific plants involved. A typical estuarine shore (from seaward in) might have successive zones dominated by:

1 Suaeda (alkali seepweed)

2 Spartina (cord grass)

3 Halimione (sea purslane)

4 Puccinellia (alkaligrass) and others

5 Juncus (rush)

C Mangrove vegetation replaces salt marshes in tropical and subtropical regions. Two most widespread genera are:

1 Rhizophora, the red mangrove occupies the outer pioneer zone. Roots are borne on downward curving branches or rhizophores. The resulting tangle reduces tidal currents and promotes deposition of solids.

2 Avicennia, the black mangrove, usually forms a shoreward zone. It depends on aerial roots, which emerge from the ground a short distance from the tree, rather than prop roots.

3 Examples have been given of open shoal areas being transformed into thick swamp forest in some 30 years through this process.

D Sea grass communities, whether composed of *Zostera* (eel grass) in Northern waters or *Thalassia* (turtle grass) or *Cymodocea* (Manatee grass) in the tropics, are recognizable as an entity wherever found. A soft substratum near low water is required, and each has a similar distinct assemblage of molluscs, crustacenas, and other invertebrates.

1 The destruction of this community by bulkheading and filling has far-reaching effects on the stability of such bottom areas.

2 Destruction of these plants by disease, such as the epidemics which decimated the *Zostera* eel grass community in the thirties created both erosion problems and also brought about far-reaching biotic community changes which only became reestablished with the return of the eel grass.

IV In comparison to other living organisms the aquatic plants or macrophytes have been seriously neglected. Man's increased activities have favored some plants (which we call "weeds") through eutrophication and diminished others (which we call a valuable resource loss) through dredging and filling operations. These events demand reassessment of knowledge about the ecology of these plants and increased contributions toward increasing that information.

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AN ARTIFICIAL KEY TO SOME COMMON AQUATIC PLANTS

(Freshwater, Estuarine, and Marine)

I Specific identification of aquatic plants often requires microscopic examination of parts which may not always be available to the investigator (for example, fruiting bodies and/or seeds which are seasonal or produced only rarely).

Because of this, some groups are more difficult to identify. *Potamogeton* is a varied and difficult genus, although Ogden's Key gives help where only vegetative parts are available. *Najas* and *Myriophyllum* are often difficult.

In the Hydrocharitaceae, *Hydrilla*, *Egeria*, and *Elodea* (*Anacharis* is an obsolete name for the latter two) are sometimes confused, and the serious student may need to turn to the specialist in this group (see Blackburn et al for a discussion of this problem.

For a detailed list of references on classification see Sculthorpe (p. 16-20) where these are listed by family. The following key will aid the common plant groups. It is divided as follows:

A) Plants floating on water surface.

B) Plants submersed beneath water surface.

C) Plants erect and emersed; rooted to the substratum and extending upward out of water.

D) Submersed "sea grasses".

Manuals with descriptive comments and figures for specific identification are listed in part under references.

To use the key, select the proper group (A, B, C, D) and read the description in the first couplet. The description that best fits the unknown specimen will indicate either the plant group or genus to which the specimen may belong or an additional couplet, in which case the process is repeated until the description for a particular plant or genus best fits the unidentified specimen. An asterisk * indicates that distribution may include brackish or salt water. Common names used here (with few exceptions) are those of: Subcommittee on Standardization of Common and Botanical Names of Weeds, reprinted from *Weeds* 14 (4):347-386 (1966).

A PLANTS FLOATING ON WATER SURFACE

1. Plants very small; seldom over a centimeter along any dimension.	2
1. Plants large; usually measuring at least 0.5 decimeter along some dimension.	8
2. Plant body dichotomously 2-lobed, or repeatedly dichotomously branched.	3
2. Plant body not dichotomously branched and if 2-lobed not equally so.	4
3. Divisions of plant body fine and many; plant body usually floating below surface.	*Riccia fluitans* L.
3. Divisions of plant body coarse, 2-lobed; floating on surface.	*Ricciocarpus natans* L.
4. Plants floating on surface.	5
4. Plants floating just below water surface; plant body made up of a clump of short filaments.	*Wolffiella floridana* Sm.
5. Plant body of small overlapping scales.	*Azolla*
5. Plant body simple or compound, made up of rounded floating leaves.	6

6. Plants simple, extremely minute, appearing as grains on surface of water.	watermeal *Wolffia*
6. Plants compound, made up of several rounded-oblong disk-like bodies, floating on surface of water.	7
7. Plant body inconspicuously nerved, rootlets 1 per disk.	star duckweed *Lemna*
7. Plant body conspicuously nerved, rootlets 2 to several per disk.	giant duckweed *Spirodela polyrhiza* L.
8. Leaves broad and blade-like, sometimes inflated near base.	9
8. Leaves (plant body in Riccia) narrow or finely divided.	12
9. Leaves large and dilated with inflated petioles.	waterhyacinth *Eichhornia crassipes* Mart.
9. Leaves normally expanded.	11
10. Leaves bearing plantlets around the margin.	floating fern *Ceratopteris*
10. Leaves not bearing plantlets.	11
11. Floating-leafed plants with leaves attached to the bottom by a bare unbranched stem of varying length.	15
11. Roots usually suspended free in the water, with no connection to lake bottom; capable of drifting.	12
12. Leaves wide to the base, without petioles.	water lettuce *Pistia stratiotes* L.
12. Leaves mostly differentiated into blades and petioles.	frogbit *Limnobium spongia* Basc.
13. Plant body repeatedly dichotomously branched.	*Riccia fluitans* L.
13. Leaves not dichotomously branched.	14
14. Leaves entire not dissected or bearing bladders, and whorled.	*Elodea*
14. Leaves dissected and bearing bladders.	bladderwort *Utricularia*
15. Stem attached to middle of leaf.	16
15. Stem attached at the summit of a deep notch in the leaf.	17
16. Leaves oval, not more than 3 inches wide, with supple stem attached to the middle of the leaf.	watershield, *Brasenia schreberi* Gmelin
16. Circular leaf with a long, fairly rigid stem attached to the middle of the leaf, leaves 6 inches or more wide sometimes supported by the stem above the water level.	american lotus *Nelumbo*
17. Circular or heart-shaped leaf with the veins radiating from the mid-rib nearly to the margin without forking; floating yellow flowers.	yellow pond lily *Nuphar*
17. Circular leaf with much-forked veins radiating to the margin, white, or pink floating flowers.	*white water lily *Nymphaea*

B PLANTS SUBMERSED BENEATH WATER SURFACE

1. Plant body made up of stems bearing whorled, smooth, brittle branches, easily snapped with a slight pressure; plants with a musky odor, no roots, often with a limy encrustation.	*green alga, muskgrass, Chara
1. Plant body not as described.	2
2. Plant attached to substrate by holdfasts or haptera, not rooted.	3
2. Plant not so attached.	4
3. Plant attached to stones by haptera (roots not attached) and tough stems forming a dull-green tangle.	riverweed, Podostemum ceratophyllum
3. Plants single shoots attached to substrate by holdfasts.	red alga Lemanea
4. Without true roots, flowers or vascular bundles.	Division Bryophyta, Mosses and Liverworts 5
4. Usually with true roots and with vascular bundles.	Division Angiospermae. True flowering plants 6
5. Leaves without midrib, arranged in two opposite rows, usually with a part folded under.	Order Jungermanniales, Porella
5. Leaves most often with midrib, usually arranged equally around the stem, not curved under.	Order Musci, Leptodictyum, Fontinalis, and Fissidens
6. Submerged leaves bearing small bladders, leaves irregularly forked.	bladderwort Utricularia
6. Submerged leaves not bladder bearing.	7
7. Submerged leaves compound, made up of narrow segments or leaflets.	8
7. Submerged leaves simple, made up of a single narrow blade.	11
8. Submerged leaves with one central axis, leaves feather-like, branches in whorls about the stem, stems usually very lax.	*water milfoil Myriophyllum
8. Submerged leaves irregularly forking.	9
9. Submerged leaves singly and alternately or irregularly borne; leaves many branches, irregularly forked and appearing as tufts of numerous thread-like projections attached to the center stem.	*water buttercup Ranunculus
9. Submerged leaves borne opposite each other on stem or whorled.	10
10. Leaves stalked, fan-like, extending from opposite sides of the stem; leaflets not toothed.	fanwort Cabomba caraliniana Gr.
10. Stems with whorls of stiff, forked leaves; leaflets with toothed or serrated margins (small barbs) on one side; plant without true roots.	coontail Ceratophyllum

11.	Submerged leaves long and ribbon-like, at least 1/10 inch wide.	12
11.	Submerged leaves not ribbon-like; often thread-like but if wider than 1/10 inch, less than 1 inch long.	22
12.	Leaves scattered along the stem.	13
12.	Leaves all borne from one point.	21
13.	Leaves with mid-ribs evident when held against bright light, many species with great diversity in leaf forms.	* pondweed *Potamogeton* 14
13.	Leaves without mid-ribs evident when held against bright light.	water star grass *Heteranthera*
14.	Plants with both floating and submerged leaves, the floating leaves with expanded blades and differing from those submerged.	15
14.	Plants with all leaves alike and submerged.	18
15.	Floating leaves, heart-shaped at the base, 1 to 4 inches long, waxy in appearance.	floating pondweed *Potamogeton natans* L.
15.	Floating leaves rounded at the base.	16
16.	Floating leaves with 30 to 50 nerves; submerged leaves about three times as long as broad.	large leaf pondweed *Potamogeton amplifolius* Tuckerman
16.	Floating leaves with less than 30 nerves.	17
17.	Upper submerged leaves with long stalks.	American pondweed *Potamogeton nodosus* Poiret
17.	Submerged leaves not as above but with an abrupt awl-shaped tip.	pondweed *Potamogeton angustifolius* Berchtold
18.	Margins of the thin leaves crimped and toothed, the marginal serrations visible to the naked eye.	* curlyleaf pondweed *Potamogeton crispus* L.
18.	Margins of leaves not visibly toothed.	19
19.	Leaves minutely toothed on the margins, visible when magnified; leaves extending stiffly in opposite directions so that whole plant appears flat; only midvein prominent.	Robbins pondweed *Potamogeton robbinsii* Oakes
19.	Not as above	20
20.	Stems much flattened and winged, about as wide as the leaves; leaves 1/12 to 1/5 inch wide.	flatstem pondweed *Potamogeton zosteriformis* Fernald
20.	Leaves threadlike, long, rounded, and slender, rarely exceeding 1/10 inch wide, oriented into a lax, diffuse, branched spray. The "bunched" appearance of the threadlike rounded leaves as they float in the water readily distinguished sago pondweed from others of group.	* sago pondweed *Potamogeton pectinatus* L.

21. Leaves very long and ribbonlike; when examined with hand lens, showing a central dense zone and a peripheral less dense zone; flowers borne on a long stem that forms a spiral after fertilization.	* Vallisneria
21. Leaf, when examined with hand lens not showing zones as above.	waterplantains, Alismataceae
22. Leaves whorled, 3 - 8 in upper whorls.	Elodea, Egeria, Hydrilla
22. Leaves alternate or opposite.	23
23. Leaves alternate, leaf-base apparently inflated.	* widgeongrass, Ruppia maritima L.
23. Leaves opposite.	24
24. All leaves long and narrow.	25
24. Upper leaves shorter and broader.	waterstarwort, Callitriche
25. Leaves dilated at base.	* naiad, Najas
25. Leaves with narrow bases.	* horned pondweed, Zannichiellia palustris L.

C PLANTS ERECT AND EMERSED; ROOTED TO THE SUBSTRATUM AND EXTENDING UPWARD OUT OF THE WATER.

1. Leaves more than 10 times as long as broad.	2
1. Leaves less than 10 times as long as broad.	12
2. Base of stem triangular in cross section, the three angles in some cases so rounded as to make the stem appear almost round.	3
2. Base of stem not triangular.	5
3. Three cornered seeds, usually straw colored, enclosed within a loose elongated sac; a low-growing grasslike plant.	sedge, Carex
3. Seeds not enclosed in a loose elongated sac.	4
4. A single flower or seed-bearing struture on the tip of the stem.	spikerush, Eleocharis
4. Stem with one or more leaves extending beyond the spike or seed-bearing structure. (The hardstem bulrush has long, hard, slender, dark olive-green stems, 1/8 to 3/8 inch at the base, extending 3 to 5 feet above the water surface; the softstream bulrush has soft stems of light green color, 3/10 to 1 inch thick at the base.)	*bulrush, Scirpus
5. Leaf with a collarlike appendage, membranous or composed of hairs at the junction of the leaf blade and that part of the leaf that is wrapped around the stem.	6
5. Leaf without collarlike appendage mentioned above.	9

6. Seed or flower-bearing structure composed of scales with fringed margins and overlapping in a single row.	Cutgrass, *Leersia*
6. Flower-bearing structure not as above.	7
7. Flowering heads composed of small seeds with long silky hairs, appearing as a silky mass. The rootstocks are stout, making it a difficult plant to pull up. Plants are 6 to 12 feet tall.	common reed, *Phragmites*
7. Flowering heads not appearing as a silky mass.	8
8. Flowering part of plant much branched, but not as closely packed as in *Phragmites*. Seeds much larger, about 3/4 inch long. Plants with short roots and easily pulled up.	wildrice, *Zizania aquatica* L.
8. Spikelets, 6 mm long or more appressed along one side of rachis, grass growing in clumps or solid stands.	*cordgrass, *Spartina*
9. None of the veins more prominent than others.	10
9. Midvein more prominent than others.	11
10. Flowers borne in closely packed cylindrical spikes, seeds very small. (The common cattail has flat leaves about 1 inch wide; the narrow-leaved cattail has leaves somewhat rounded on the back that are 1/8 to 7/8 inch wide.)	Cattail, *Typha*
10. Flowers in spherical heads, seeds larger, up to size of corn kernel; leaves shallowly and broadly triangular in cross-section.	burreed, *Sparganium*
11. Plants aromatic when crushed.	sweetflag *Acorus calamus* L.
11. Plants not aromatic when crushed, flowers large and showy.	yellow iris *Iris pseudacorus* L.
12. Leaves arising at intervals along the stem.	13
12. Leaves arising at base of the plant.	14
13. Plants with jointed stems, swollen at the joints, or with creeping rootstocks; stems with alternate, simple leaves.	smartweed, *Polygonum*
13. Stems prostrate or creeping, branched, and often jointed and rooted at the joints; leaves opposite; spreading plant, often forming floating mats over extensive water areas crowding out other plants; broken off branch fragments root readily, and stems may elongate as much as 200 inches in one season.	alligatorweed, *Alternanthera philoxeroides* Mart.
14. Fleshy or tuber-bearing rootstocks and rosettes of sheathing basal leaves.	15
14. Not as above, floating plants.	16

15. None of the veins more prominent than others.	*arrowhead *Sagittaria*
15. Midvein and those descending into the lobes more prominent than others.	arrow arum *Peltandra virginia* L.
16. Plants floating with fibrous, branched roots and rosettes of stalked leaves, the leaf stalks often inflated and bladder-like.	waterhyacinth *Eichhornia crassipes* Mart.
16. Plants with floating rosettes of stalked leaves, commonly several rosettes produced on branches of the same plant at the end of flexible, cardlike, sparsely-branched submerged stems; plant thrives at depths of 2 to 5 feet and favors muddy bottoms with high organic content; leaf stalks inflated, but not as conspicuously as in waterhyacinth.	water-chestnut, *Trapa natans* L.

D SUBMERSED "SEA GRASSES"

1. Leaves round in cross section.	manateegrass, *Cymodocea manatorum*
2. Leaves flat.	3
3. Leaves widest at or above the middle.	*Halophila*
3. Leaves uniform width.	4
4. Leaf tip blunt.	turtlegrass, *Thalassia testudinum*
4. Leaf tip pointed.	5
5. Leaf tip single.	eelgrass, *Zostera marina*
5. Leaf tip 3-pointed.	shoalgrass, *Diplanthera wrightii*

ACKNOWLEDGMENT:

This outline was adapted from Keys of Mackenthun and Ingram (1967); Robertson and Eyles (1963); and Humm (1956). The figures are from Eyles and Robertson and Hotchkiss (1967).

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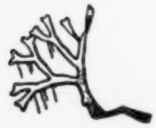
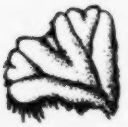
This outline was prepared by R.M. Sinclair, Aquatic Biologist, National Training Center, Water Programs Operations, EPA, Cincinnati, OH 45268.

Group A

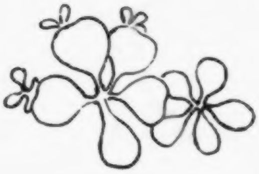
FLOATING PLANTS



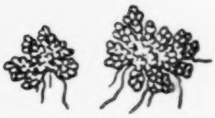
Riccia



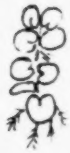
Ricciocarpus



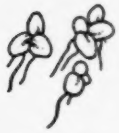
Ceratopteris



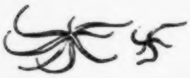
Azolla



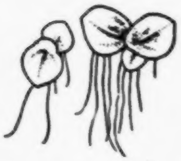
Salvinia



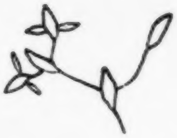
Lemna minor



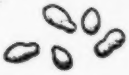
Wolffiella



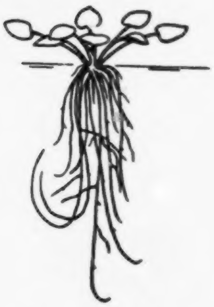
Spirodela



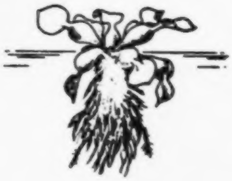
Lemna triscula



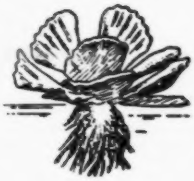
Wolffia



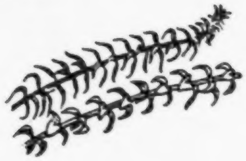
Limnobium



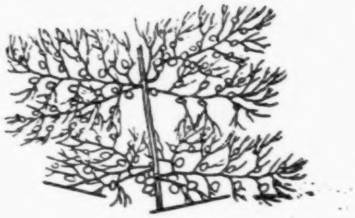
Eichornia



Pistia



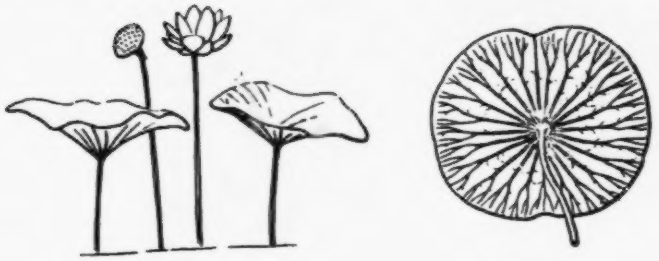
Elodea



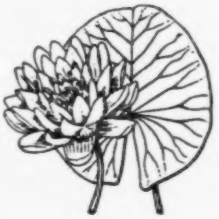
Ultricularia

Group A

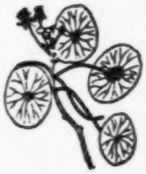
FLOATING PLANTS (Cont.)

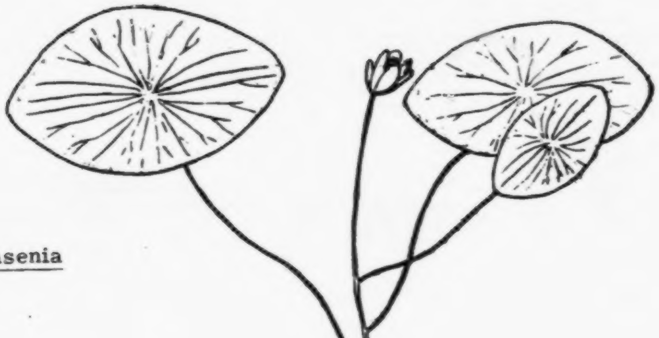


Nelumbo

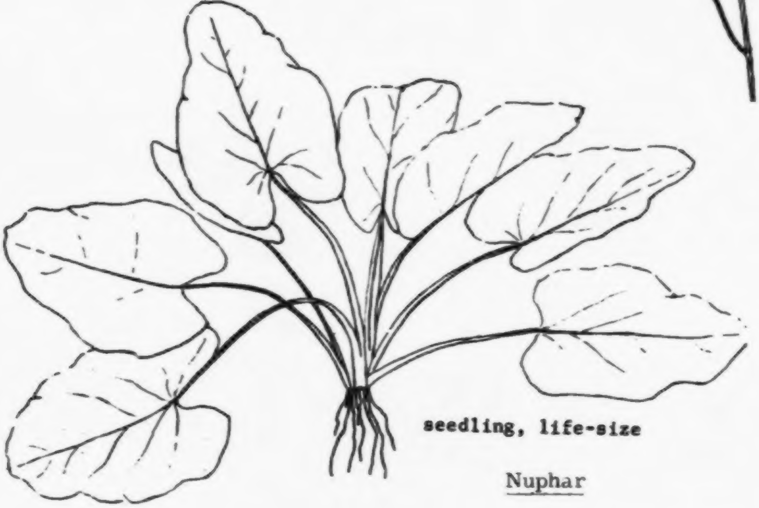


Nymphaea

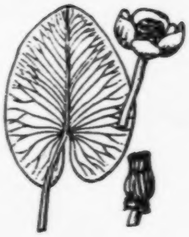




Brasenia

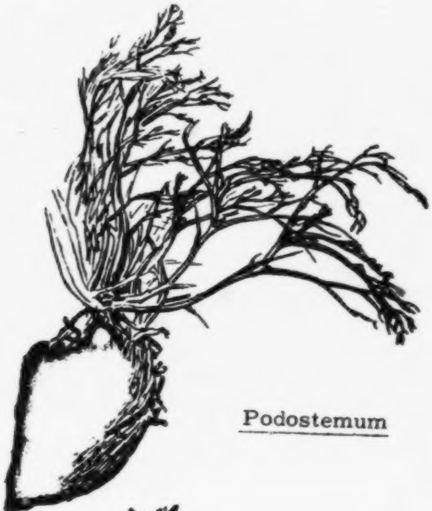


seedling, life-size

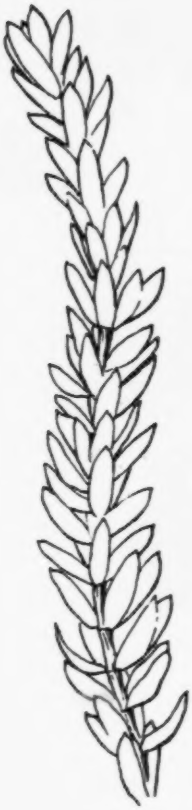


Nuphar

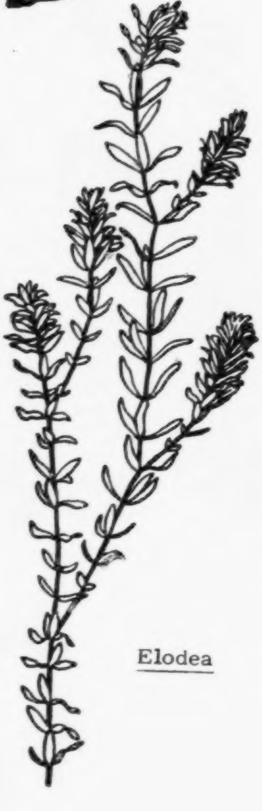
Group B
SUBMERSED



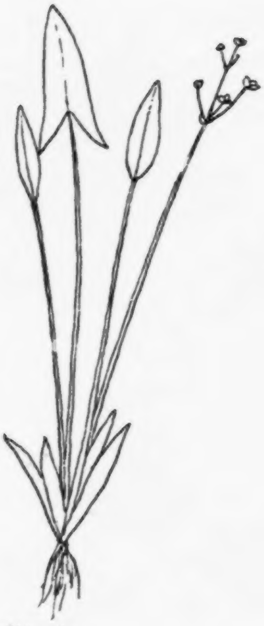
Podostemum



Egeria



Elodea



Sagittaria

Group B
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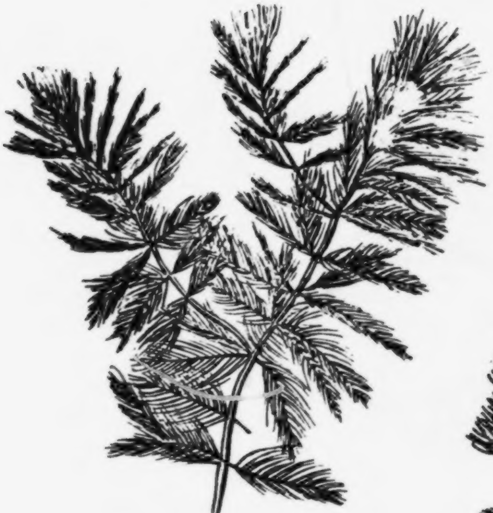
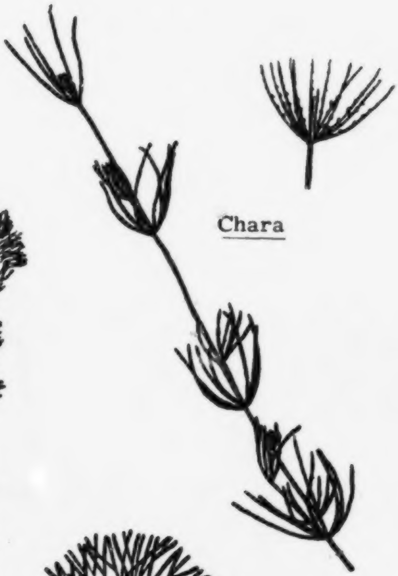
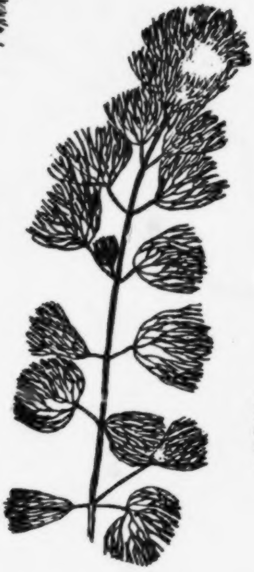
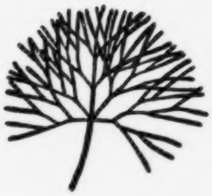


Myriophyllum

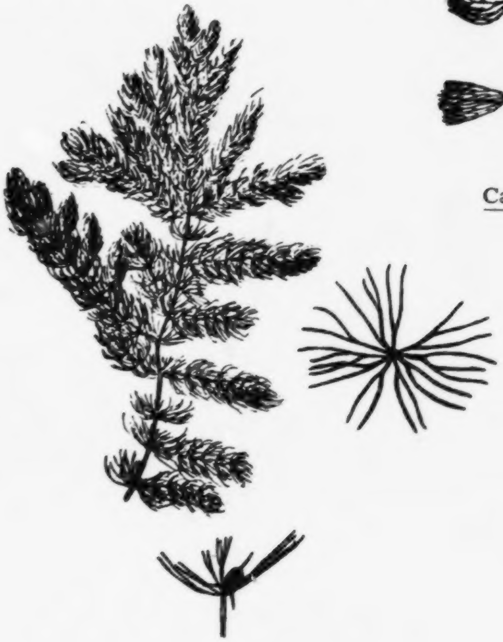


Chara

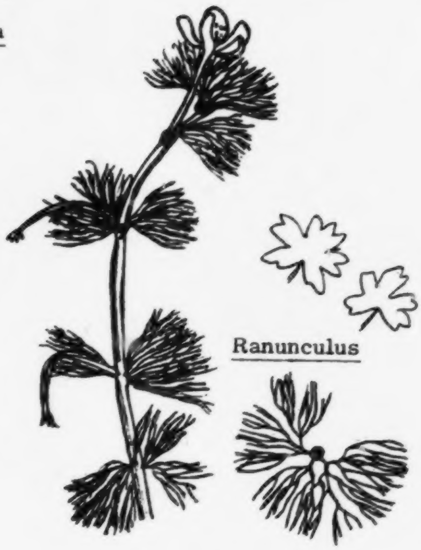




Cabomba



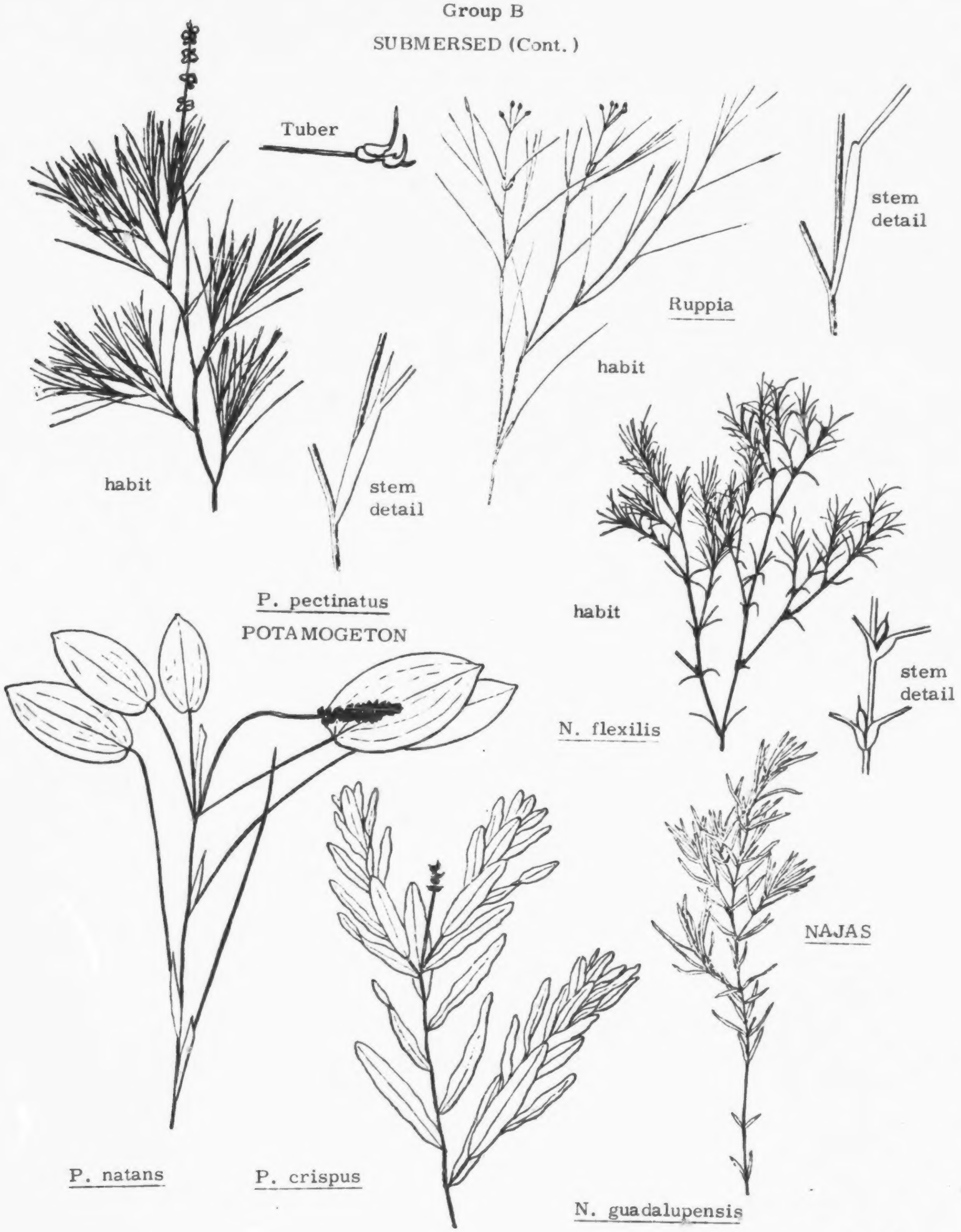
Ceratophyllum



Ranunculus

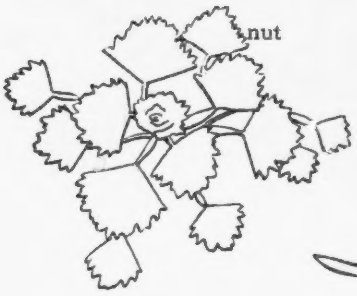
Group B

SUBMERSED (Cont.)

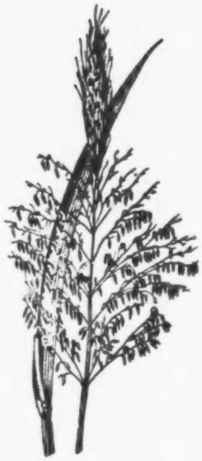

Tuber
habit
stem detail
P. pectinatus
POTAMOGETON
habit
Ruppia
stem detail
habit
stem detail
N. flexilis
NAJAS
P. natans
P. crispus
N. guadalupensis

Group C

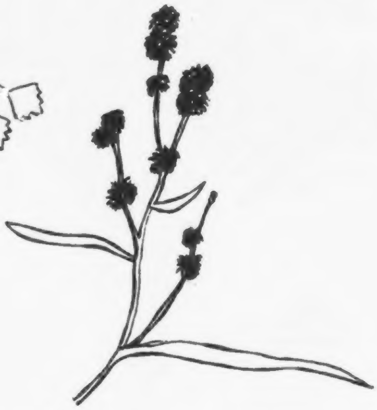
EMERSED



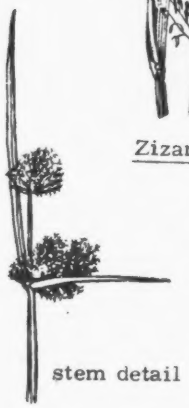
Trapa



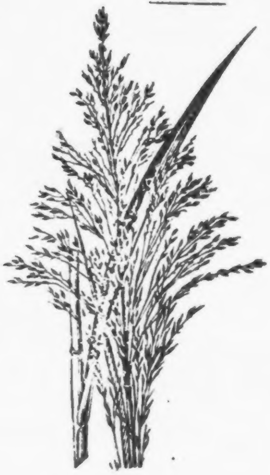
Zizania



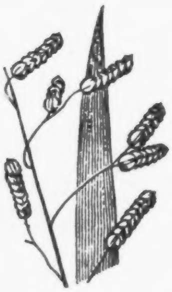
Sparganium


stem detail

Cyperus



Zizaniopsis



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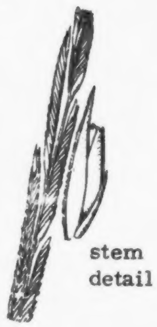
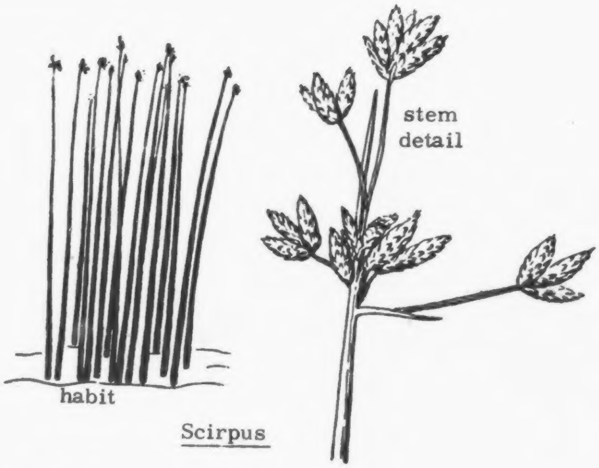
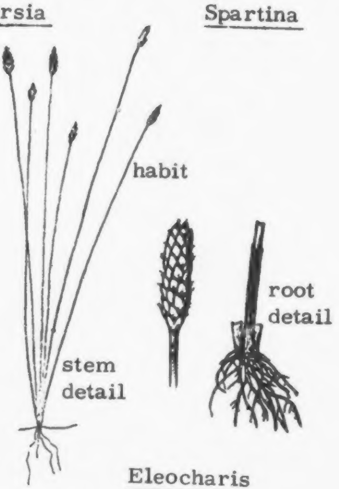

stem
detail

Spartina


habit
stem
detail

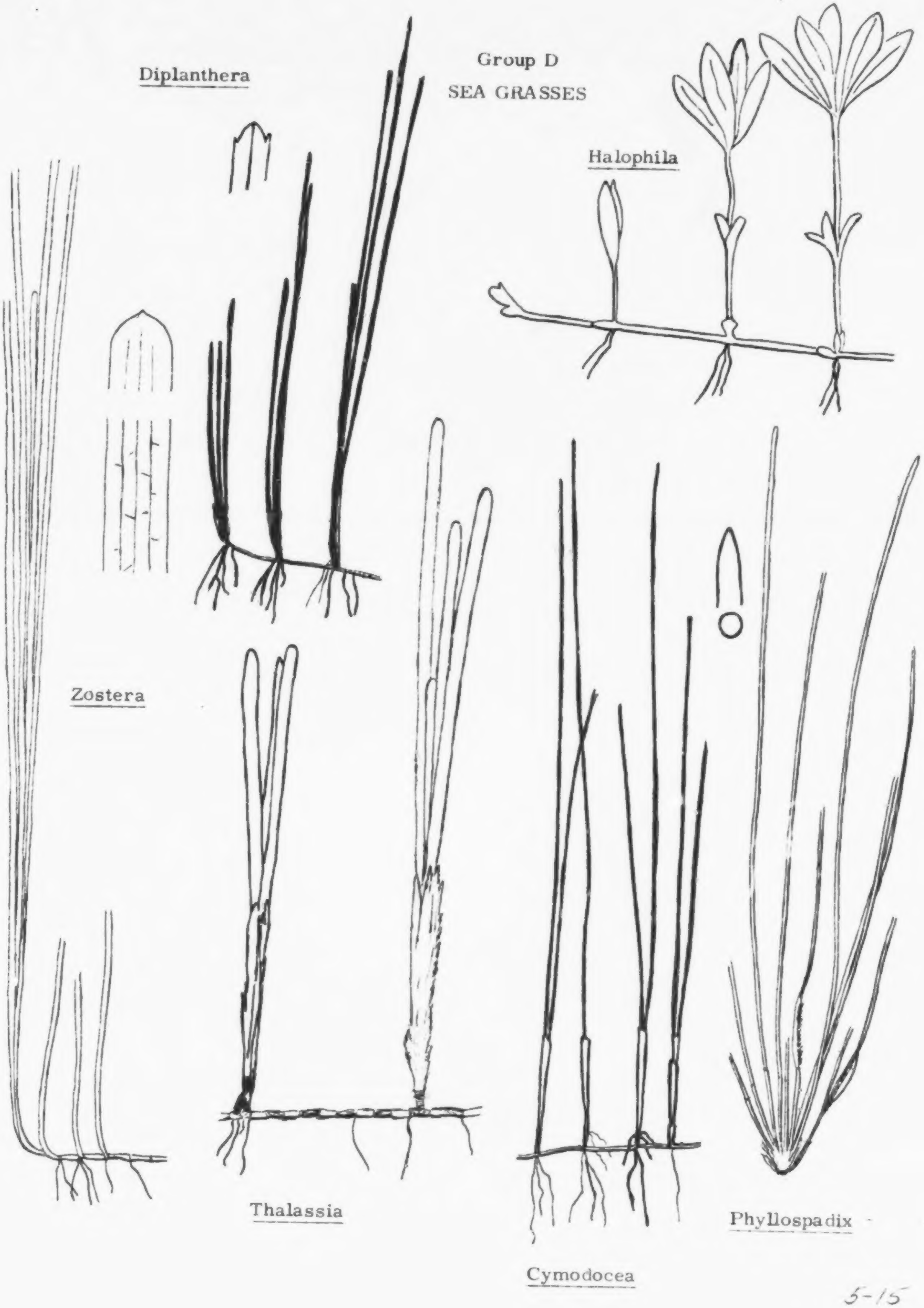
Scirpus


habit
stem
detail
root
detail

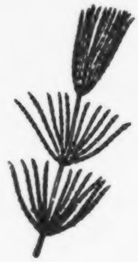
Eleocharis

5-14

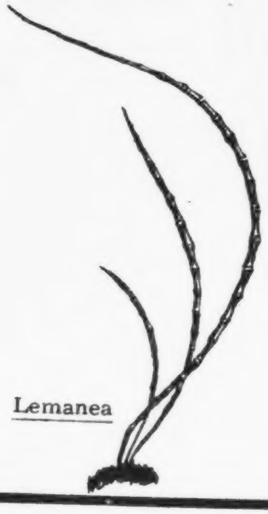
Group D
SEA GRASSES


Diplanthera
Halophila
Zostera
Thalassia
Cymodocea
Phyllospadix

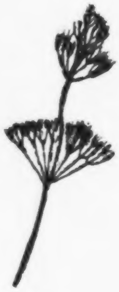
AQUATIC MACROPHYTES - ALGAE AND BRYOPHYTES



Chara

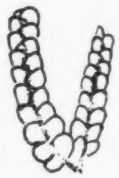


Lemanea



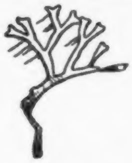
Nitella

Division ALGAE

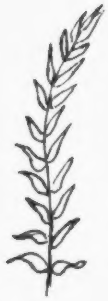


Porella

"Liverworts"
Class Hepaticae

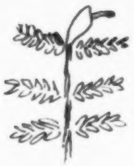


Riccia



Leptodictyum

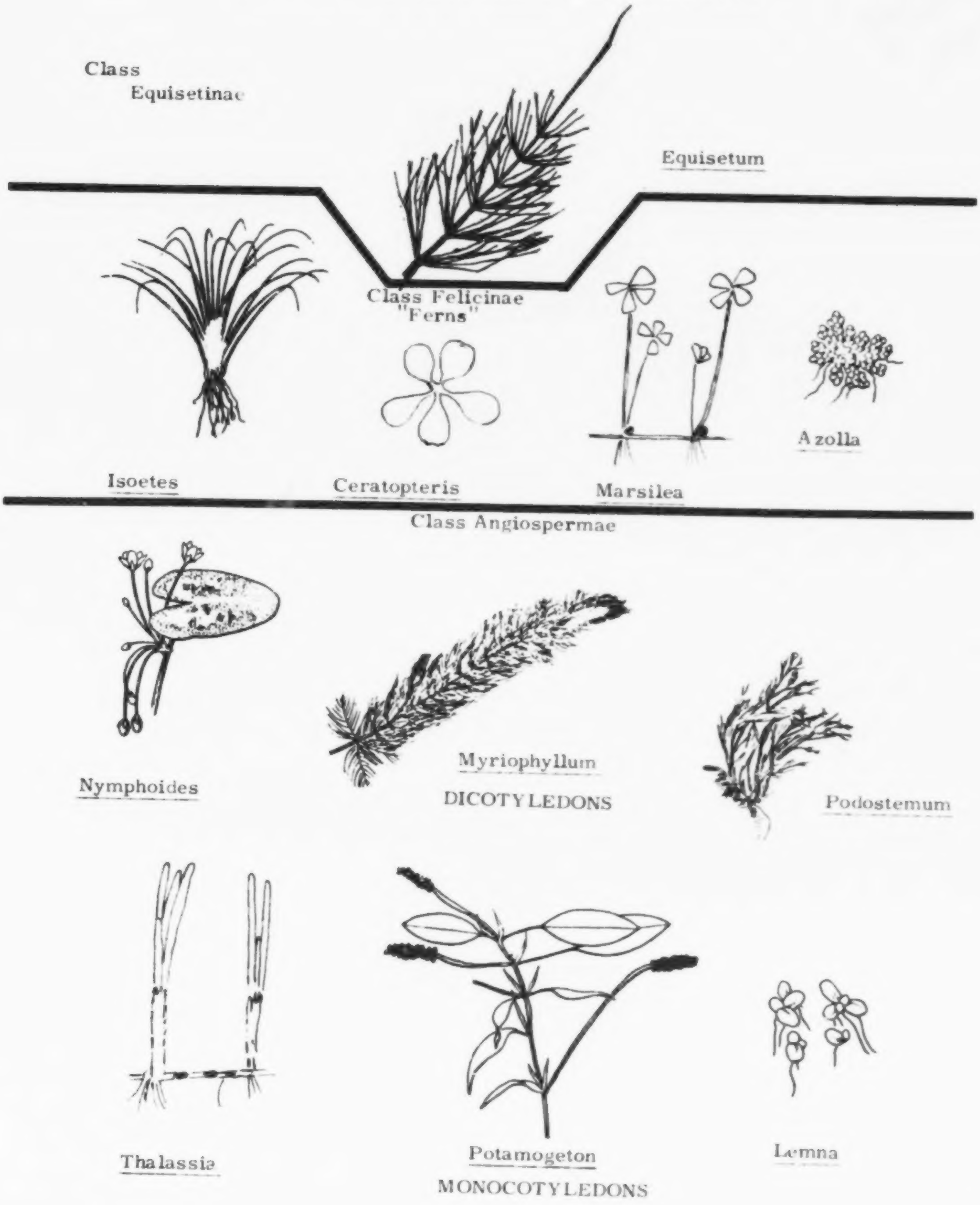
"Mosses"
Class Musci



Sphagnum

Division BRYOPHYTA

AQUATIC VASCULAR PLANTS - TRACHEOPHYTA


Class
Equisetinae
Equisetum
Class Felicinae
"Ferns"
Isoetes
Ceratopteris
Marsilea
Azolla
Class Angiospermae
Nymphoides
Myriophyllum
DICOTYLEDONS
Podostemum
Thalassia
Potamogeton
MONOCOTYLEDONS
Lemna

KEY TO SELECTED GROUPS OF FRESHWATER ANIMALS

The following key is intended to provide an introduction to some of the more common freshwater animals. Technical language is kept to a minimum.

In using this key, start with the first couplet (1a, 1b), and select the alternative that seems most reasonable. If you selected "1a" you have identified the animal as a member of the group, Phylum PROTOZOA. If you selected "1b", proceed to the couplet indicated. Continue this process until the selected statement is terminated with the name of a group.

If you wish more information about the group, consult references. (See reference list.)

1a	The body of the organism comprising a single microscopic independent cell, or many similar and independently functioning cells associated in a colony with little or no difference between the cells, i.e., without forming tissues; or body comprised of masses of multinucleate protoplasm. Mostly microscopic, single celled animals. Phylum PROTOZOA	
1b	The body of the organism comprised of many cells of different kinds, i.e., forming tissues. May be microscopic or macroscopic.	2
2a	Body or colony usually forming irregular masses or layers sometimes cylindrical, goblet shaped, vase shaped, or tree like. Size range from barely visible to large.	3
2b	Body or colony shows some type of definite symmetry.	4
3a	Colony surface rough or bristly in appearance under microscope or hand lens. Grey, green, or brown. Sponges. Phylum PORIFERA (Fig. 1)	
3b	Colony surface relatively smooth. General texture of mass gelatinous, transparent. Clumps of minute individual organisms variously distributed. Moss animals, bryozoans. Phylum BRYOZOA (Fig. 2)	
4a	Microscopic. Action of two ciliated (fringed) lobes at anterior (front) end in life often gives appearance of wheels. Body often segmented, accordian-like. Free swimming or attached. Rotifers or wheel animalcules. Phylum TROCHELMINTHES (Rotifera) (Fig. 3)	
4b	Larger, wormlike, or having strong skeleton or shell.	5
5a	Skeleton or shell present. Skeleton may be external or internal.	15
5b	Body soft and/or wormlike. Skin may range from soft to parchment-like.	6
6a	Three or more pairs of well formed jointed legs present. Phylum ARTHROPODA (Fig. 4)	19
6b	Legs or appendages, if present, limited to pairs of bumps or hooks. Lobes or tenacles, if present, soft and fleshy, not jointed.	7
7a	Body strongly depressed or flattened in cross section.	8
7b	Body oval, round, or shaped like an inverted "U" in cross section.	10
8a	Parasitic inside bodies of higher animals. Extremely long and flat, divided into sections like a Roman girdle. Life history may involve an intermediate host. Tape worms. Class CESTODA (Fig. 5)	
8b	Body a single unit. Mouth and digestive system present, but no anus.	9
9a	External or internal parasite of higher animals. Sucking discs present for attachment. Life history may involve two or more intermediate hosts or stages. Flukes. Class TREMATODA	
9b	Free living. Entire body covered with locomotive cilia. Eye areas in head often appear "crossed". Free living flatworms. Class TURBELLARIA (Fig. 6)	
10a	Long, slender, with snake-like motion in life. Covered with glistening cuticle. Parasitic or free-living. Microscopic to six feet in length. Round worms. Phylum NEMATHELMINTHES (Fig. 7)	
10b	Divided into sections or segments	11

10c Unsegmented head blunt one or two retractile tentacles. Flat pointed, tail. 18

11a Head a more or less well-formed, hard, capsule with jaws, eyes, and antennae.
Class INSECTA order DIPTERA (Figs. 8A, 8C)

11b Head structure soft, except jaws (if present). Fig. 8E.) 12

12a Head conical or rounded, lateral appendages not conspicuous or numerous. 13

12b Head somewhat broad and blunt. Retractile jaws usually present. Soft fleshy lobes or tentacles, often somewhat flattened, may be present in the head region. Tail usually narrow. Lateral lobes or fleshy appendages on each segment unless there is a large sucker disc at rear end. 14
Phylum ANNELIDA (Fig. 9)

13a Minute dark colored retractile jaws present, body tapering somewhat at both ends, pairs or rings of bumps or "legs" often present, even near tail.
Class INSECTA Order DIPTERA (Fig. 8)

13b No jaws, sides of body generally parallel except at ends. Thickened area or ring usually present if not all the way back on body. Clumps of minute bristles on most segments. Earthworms, sludgeworms. 14
Order OLIGOCHAETA

14a Segments with bristles and/or fleshy lobes or other extensions. Tube builders, borers, or burrowers. Often reddish or greenish in color. Brackish or fresh water. Nereid worms.
Order POLYCHAETA (Fig. 9A)

14b Sucker disc at each end, the large one posterior. External blood-sucking parasites on higher animals, often found unattached to host. Leaches.
Class HIRUDINEA (Fig. 9B)

15a Skeleton internal, of true bone. (Vertebrates) 40

15b Body covered with an external skeleton or shell. (Figs. 10, 13, 17, 18, 24, 25, 28) 16

16a External skeleton jointed, shell covers legs and other appendages, often leathery in nature. 19
Phylum ARTHROPODA

16b External shell entire, not jointed, unless composed of two clam-like halves. (Figs. 10, 11, 12) 17

17a Half inch or less in length. Two leathery, clam-like shells. Soft parts inside include delicate, jointed appendages. Phyllopods or branchiopods.
Class CRUSTACEA, Subclasses BRANCHIOPODA (Fig. 12) and OSTRACODA (Fig. 11)

17b Soft parts covered with thin skin, mucous produced, no jointed legs. 18
Phylum MOLLUSCA

18a Shell single, may be a spiral cone. Snails.
Class GASTROPODA (Fig. 13)

18b Shell double, two halves, hinged at one point. Mussels, clams.
Class BIVALVIA (Fig. 10)

19a Three pairs of regular walking legs, or their rudiments. Wings present in all adults and rudiments in some larvae. 29
Class INSECTA (Figs. 22, 24D, 25, 26, 28, 29)

19b More than three pairs of legs apparently present. 20

20a Body elongated, head broad and flat

with strong jaws. Appendages following first three pairs of legs are rounded tapering filaments. Up to 3 inches long. Dobson fly and fish fly larvae.
Class INSECTA Order
MEGALOPTERA (Fig. 14)

20b Four or more pairs of legs. 21

21a Four pairs of legs. Body rounded, bulbous, head minute. Often brown or red. Water mites.

Phylum ARTHROPODA, Class
ARACHNIDA, Order ACARI
(Fig. 15)

21b Five or more pairs of walking or swimming legs; gills, two pairs of antennae. Crustaceans. 22
Phylum ARTHROPODA,
Class CRUSTACEA

22a Ten or more pairs of flattened, leaflike swimming and respiratory appendages. Many species swim constantly in life; some swim upside down. Fairy shrimps, phyllopods, or branchipods.
Subclass BRANCHIOPODA
(Fig. 16)

22b Less than ten pairs of swimming or respiratory appendages. 23

23a Body and legs inclosed in bivalved (2 halves) shell which may or may not completely hide them. 24

23b Body and legs not enclosed in bivalve shell. May be large or minute. 26
(Figs. 17, 18, 19)

24a One pair of branched antennae enlarged for locomotion, extend outside of shell (carapace). Single eye usually visible. "Water fleas"
Subclass CLADOCERA (Fig. 12)

24b Locomotion accomplished by body legs, not by antennae. 25

25a Appendages leaflike, flattened, more than ten pairs.
Subclass BRANCHIOPODA
(See 22 a)

25b Animal less than 3 mm. in length. Appendages more or less slender and jointed, often used for walking. Shells opaque. Ostracods.
(Fig. 11) Subclass OSTRACODA

26a Body a series of six or more similar segments, differing mainly in size. 27

26b Front part of body enlarged into a somewhat separate body unit (cephalothorax) often covered with a single piece of shell (carapace). Back part (abdomen) may be relatively small, even folded underneath front part. (Fig. 19b) 28

27a Body compressed laterally, i.e., organism is tall and thin. Scuds. amphipods.
Subclass AMPHIPODA (Fig. 17)

27b Body compressed dorsoventrally, i.e., organism low and broad. Flat gills contained in chamber beneath tail. Sowbugs.
Subclass ISOPODA (Fig. 18)

28a Abdomen extending straight out behind, ending in two small projections. One or two large masses of eggs are often attached to female. Locomotion by means of two enlarged, unbranched antennae, the only large appendages on the body. Copepods.
Subclass COPEPODA (Fig. 19)

28b Abdomen extending out behind ending in an expanded "flipper" or swimming paddle. Crayfish or craw fish. Eyes on movable stalks. Size range usually from one to six inches.
Subclass DECAPODA

29a Two pairs of functional wings, one pair may be more or less hardened as protection for the other pair. Adult insects which normally live on or in the water. (Figs. 25, 28) 39

29b No functional wings, though pads in which wings are developing may be visible. Some may resemble adult insects very closely, others may differ extremely from adults. 30

30a External pads or cases in which wings develop clearly visible.(Figs. 24, 26, 27) 35

30b More or less wormlike, or at least no external evidence of wing development. 31

31a No jointed legs present. Other structures such as hooks, sucker discs, breathing tubes may be present. Larvae of flies, midges, etc.
Order DIPTERA (Fig. 8)

31b Three pairs of jointed thoracic legs, head capsule well formed. 32

32a Minute (2-4mm) living on the water surface film. Tail a strong organ that can be hooked into a "catch" beneath the thorax. When released animal jumps into the air. No wings are ever grown. Adult springtails.
Order COLLEMBOLA (Fig. 20)

32b Larger (usually over 5 mm) wormlike, living beneath the surface. 33

33a Live in cases or webs in water. Cases or webs have a silk foundation to which tiny sticks, stones, and/or bits of debris are attached. Abdominal segments often with minute gill filaments. Generally cylindric in shape. Caddisfly larvae.
Order TRICHOPTERA (Fig. 21)

33b Free living, build no cases. 34

34a Somewhat flattened in cross section and massive in appearance. Each abdominal segment with rather stout, tapering, lateral filaments about as long as body is wide. Alderflies, fishflies, and dobsonflies.
Order MEGALOPTERA (Fig. 22, 14)

34b Generally rounded in cross section. Lateral filaments if present tend to be long and thin. A few forms extremely flattened, like a suction cup. Beetle larvae.
Order COLEOPTERA (Fig. 23)

35a Two or three filaments or other structures extending out from end of abdomen. 37

35b Abdomen ending abruptly, unless terminal segment itself is extended as single structure.(Figs. 24A, 24C) 36

36a Mouth parts adopted for chewing. Front of face covered by extensible folded mouthparts often called a "mask". Head broad, eyes widely spaced. Nymphs of dragonflies or darning needles.
Order ODONATA (Figs.24A, 24C, 24E)

36b Mouthparts for piercing and sucking. Legs often adapted for water locomotion. Body forms various. Water bugs, water scorpions, water boatmen, backswimmers, electric light bugs, water striders, water measurers, etc.
Order HEMIPTERA (Fig. 25)

37a Tail extensions (caudal filaments) two. Stonefly larvae.
Order PLECOPTERA (Fig. 26)

37b Tail extensions three, at times greatly reduced in size. 38

38a Tail extensions long and slender. Rows of hairs may give extensions a feather-like appearance. Mayfly larvae.
Order EPHEMEROPTERA (Fig. 27)

38b Tail extensions flat, elongated plates. Head broad with widely spaced eyes, abdomen relatively long and slender. Damselfly nymths.
Order ODONATA (Fig. 24D)

39a External wings or wing covers form a hard protective dome over the inner wings folded beneath, and over the abdomen. Beetles.
Order COLEOPTERA
(Fig. 28)

39b External wings leathery at base, Membranaceous at tip. Wings sometimes very short. Mouthparts for piercing and sucking. Body form various. True bugs.
Order HEMIPTERA (Fig. 25)

40a Appendage present in pairs. (fins, legs, wings). 42

40b No paired appendages. Mouth a round suction disc. 41

41a Body long and slender. Several holes along side of head. Lampreys.
Sub Phylum VERTEBRATA,
Class CYCLOSTOMATA

41b Body plump, oval. Tail extending out abruptly. Larvae of frogs and toads. Legs appear one at a time during metamorphosis to adult form. Tadpoles.
Class AMPHIBIA

42a Paired appendages are legs 43

42b Paired appendages are fins, gills covered by a flap (operculum). True fishes.
Class PISCES

43a Digits with claws, nails, or hoofs 44

43b Skin naked. No claws or digits. Frogs, toads, and salamanders.
Class AMPHIBIA

44a Warm blooded 45

44b Cold blooded. Body covered with horny scales or plates.
Class REPTILIA

45a Body covered with feathers. Birds.
Class AVES

45b Body covered with hair. Mammals.
Class MAMMALIA

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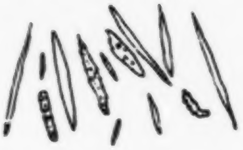
3 Eddy, Samuel. How to Know the Freshwater Fishes. Wm. C. Brown Company, Dubuque, Iowa. 1957.

4 Hubbs, C.L. and Lagler, K.F. Fishes of the Great Lakes Region. Bull. Cranbrook Inst. Science, Bloomfield Hills, Michigan. 1949.

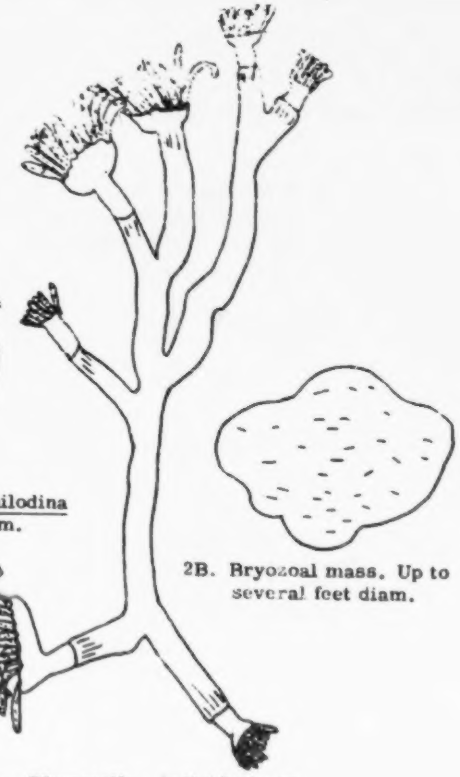
5 Lagler, K.F. Freshwater Fishery Biology. Wm. C. Brown Company, Dubuque, Iowa. 1952.

6 Trautman, M.B. The Fishes of Ohio. Ohio State University Press, Columbus. 1957. (An outstanding example of a State study).

Descriptors: Aquatic Life, Systematics.

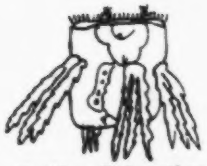


1. Spongilla spicules
Up to .2 mm. long.

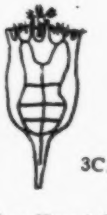


2B. Bryozoal mass. Up to several feet diam.

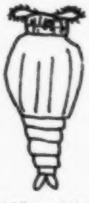
2A. Bryozoa, Plumatella. Individuals up to 2 mm. Intertwined masses may be very extensive.



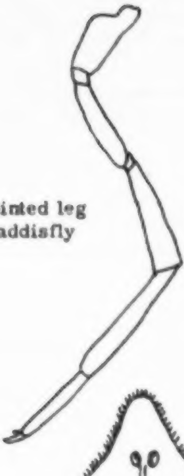
3A. Rotifer, Polyarthra
Up to .3 mm.



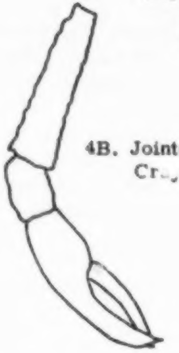
3B. Rotifer, Keratella
Up to .3 mm.



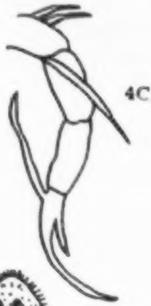
3C. Rotifer, Philodina
Up to .4 mm.



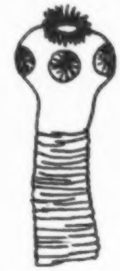
4A. Jointed leg
Caddisfly



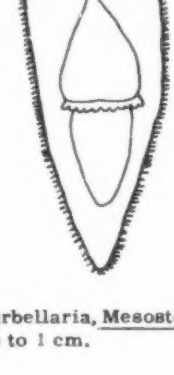
4B. Jointed leg
Crayfish



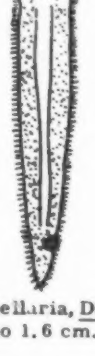
4C. Jointed leg
Ostracod



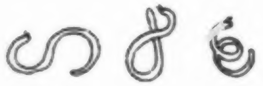
5. Tapeworm head, Taenia. Up to 25 yds. long



6A. Turbellaria, Mesostoma
Up to 1 cm.

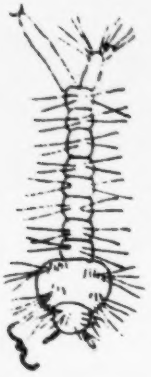


6B. Turbellaria, Dugesia
Up to 1.6 cm.

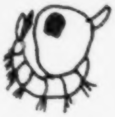


7. Nematodes. Free living forms commonly up to 1 mm., occasionally more.

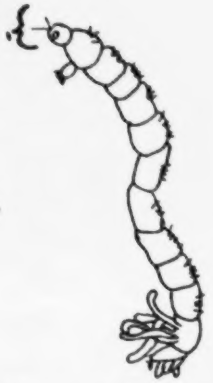
6-8



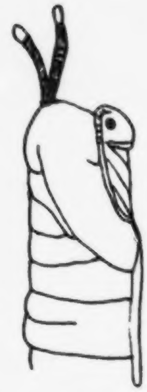
8A. Diptera, Mosquito larvae Up to 15 mm. long.



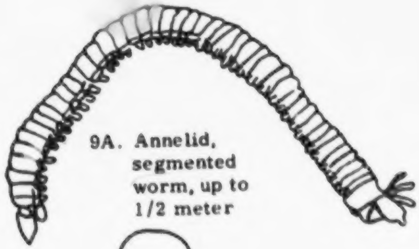
8B. Diptera, Mosquito pupa. Up to 5 mm.



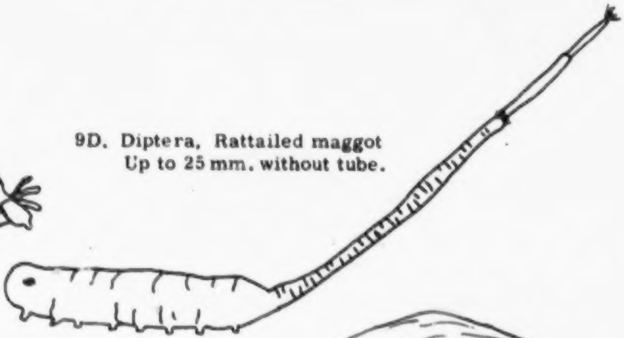
8C. Diptera, chironomid larvae. Up to 2 cm.



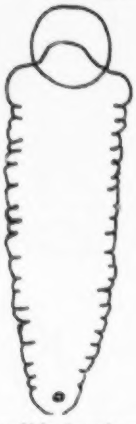
8E. Diptera, crane fly pupa. Up to 2.5 cm.



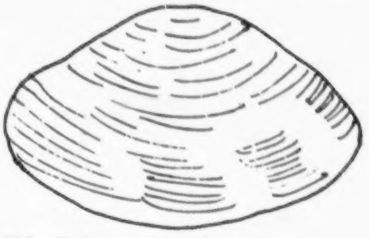
9A. Annelid, segmented worm, up to 1/2 meter



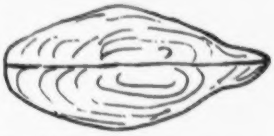
9D. Diptera, Rattailed maggot Up to 25 mm. without tube.



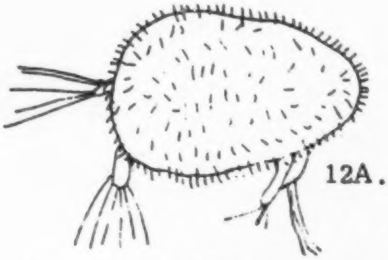
9B. Annelid, leech up to 20 cm.



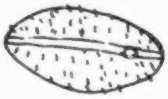
10A. Pelecyopod, Alasmidonta Side view, up to 18 cm. long.



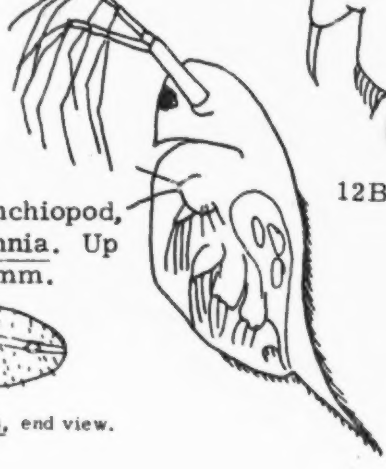
10B. Alasmidonta, end view.



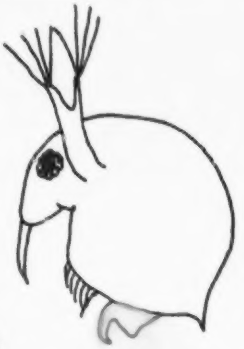
11A. Ostracod, Cypericus Side view, up to 7 mm.



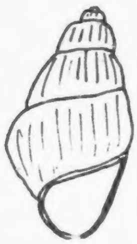
11B. Cypericus, end view.



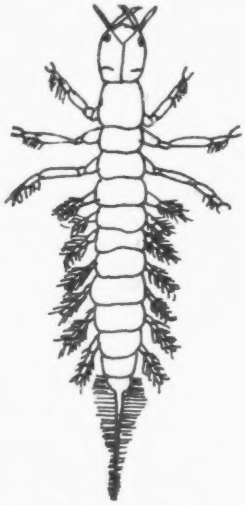
12A. Branchiopod, Daphnia. Up to 4mm.



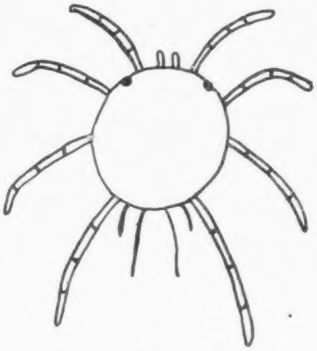
12B. Branchiopod, Bosmina. Up to 2mm.



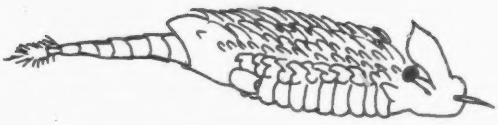
13. Gastropod, Viviparus
Up to 3 inches.



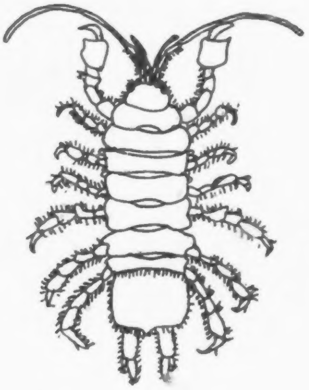
14. Megaloptera,
Alderfly larvae
Up to 25 mm.



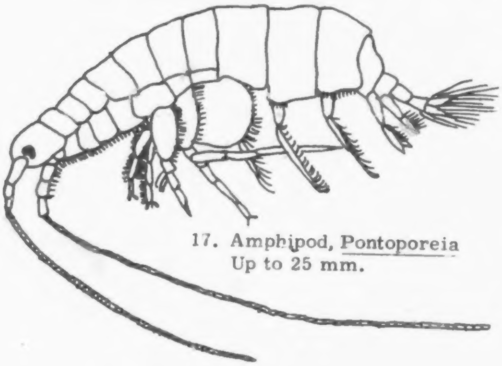
15. Water mite,
Up to 3 mm.



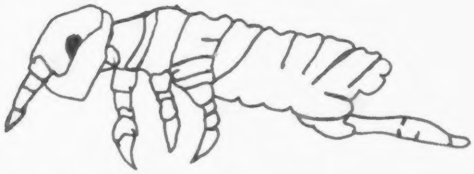
16. Fairy Shrimp, Eubranchipus
Up to 5 cm.



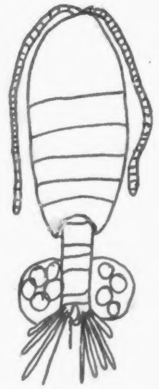
18. Isopod, Asellus
Up to 25 mm.



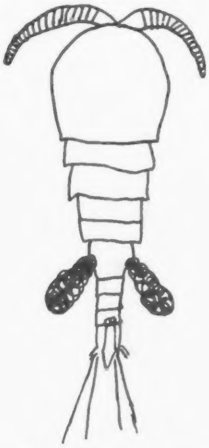
17. Amphipod, Pontoporeia
Up to 25 mm.



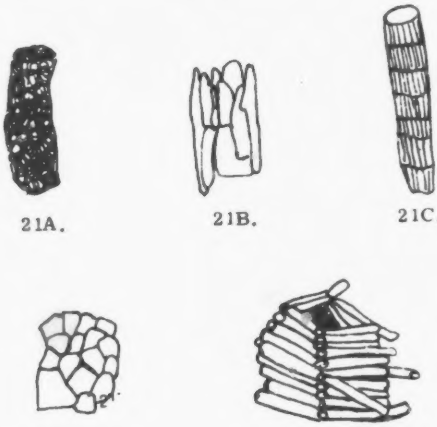
20. Collembola, Podura
Up to 2 mm. long



19A. Calanoid copepod,
Female
Up to 3 mm.



19B. Copepoid copepod,
Female
Up to 25 mm.



21A.

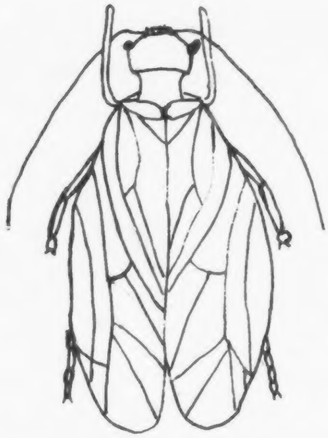
21B.

21C.

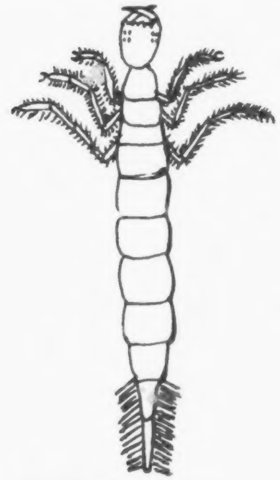
21D.

21E.

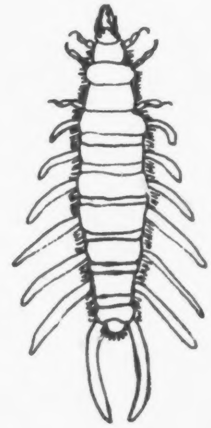
21. Tricoptera, Larvae cases, mostly 1-2 cm.



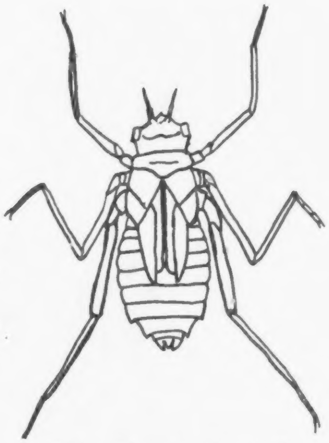
22. Megaloptera, alderfly
Up to 2 cm.



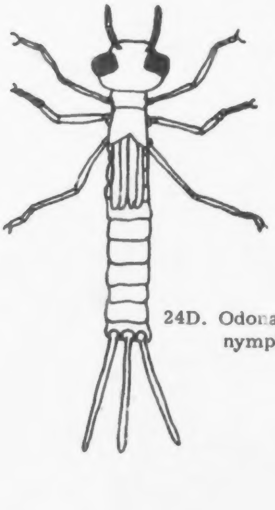
23A. Beetle larvae,
Dytisidae,
Usually about ½ cm.



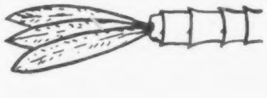
23B. Beetle larvae,
Hydrophilidae,
Usually about 1 cm.



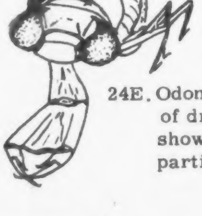
24A. Odonata, dragonfly
nymph up to 3 or 4
cm.



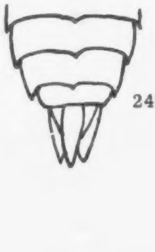
24D. Odonata, damselfly
nymph (top view)



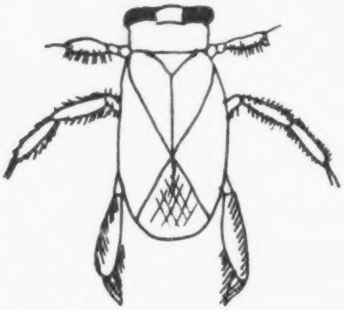
24B. Odonata, tail of
damselfly nymph
(side view)



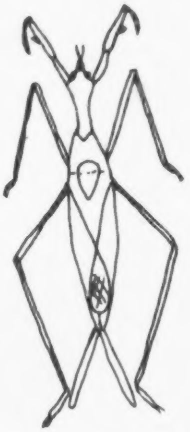
24E. Odonata, front view
of dragonfly nymph
showing "mask"
partially extended



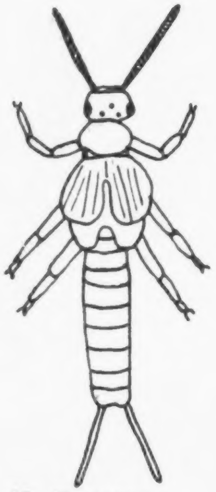
24C. Odonata, tail of
dragonfly nymph
(top view)



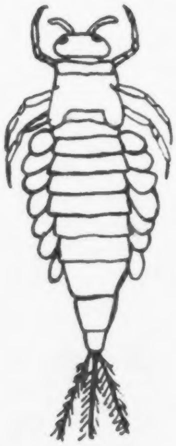
25A. Hemiptera,
Water Boatman
About 1 cm.



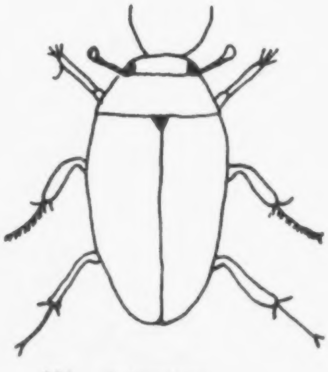
25B. Hemiptera,
Water Scorpion
About 4 cm.



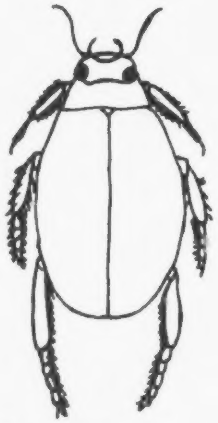
26. Plecoptera,
Stonefly nymph
Up to $\frac{1}{2}$ cm.



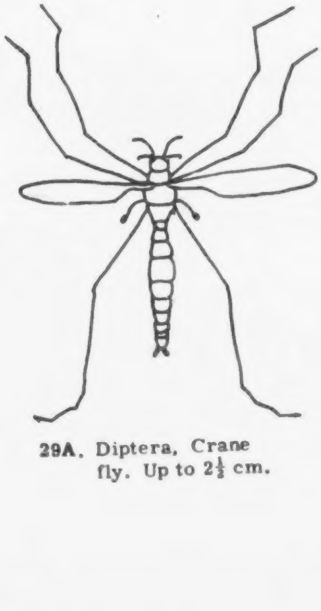
27. Ephemeroptera,
Mayfly nymph
Up to $\frac{1}{2}$ cm.



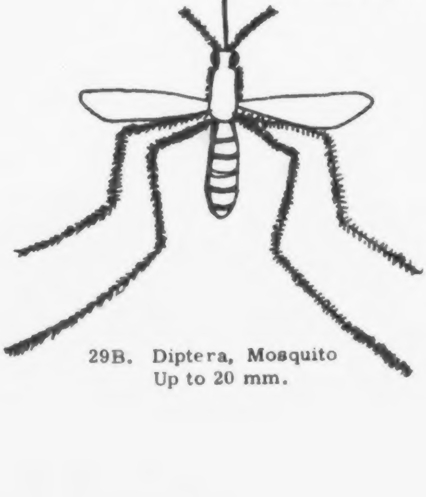
28A. Coleoptera,
Water scavenger
beetle. Up to 4 cm.



28B. Coleoptera,
Dytiscid beetle
Usually up to $2\frac{1}{2}$ cm.



29A. Diptera, Crane
fly. Up to $2\frac{1}{2}$ cm.



29B. Diptera, Mosquito
Up to 20 mm.

BIOTA OF WASTEWATER TREATMENT PLANTS (MICROSCOPIC INVERTEBRATES)

I GENERAL CONSIDERATIONS

A Community rather than individual as a unit for study of the process; quantitative relationship among different populations - "population dynamics".

B Sequential transformation of organic matter through the microbial life - a transference of materials and energy between microbial populations led to the development of functional synecology or productive ecology.

C Microbes considered here include bacteria, protozoa, and microscopic metazoa; algae and fungi are important groups included elsewhere in more detail.

D All microbial groups originate from a) the waste itself, b) washing waters, c) soil, d) dust from air, and e) incidental sources; only those members that can survive and establish themselves in the community are important; some are transient.

E Some variations in composition of the microbial community in domestic sewage treatment due to climatic and other ecological factors; industrial wastes with specific waste matter may call for development of more restricted microbial community for degradation.

F Most active microbial groups are: True bacteria, filamentous bacteria, fungi, protozoa, nematodes, rotifers, oligochaetes, and water-mites.

II BACTERIA

A No ideal method for studying distribution and ecology of bacteria in waste-treatment. Total bacterial counts made on nutrient agar or gelatine reflect only a portion of the bacterial flora present.

B Pseudomonads are probably the most versatile in their ability to attack a great variety of organic compounds, including petroleum products, phenolics, cyanides. Others, such as Achromobacter, Alcaligenes, Chromobacterium, Flavobacterium, Aerobacter, and Micrococcus, are also important genera. Actinomyces are prominent in wastes rich in cellulose and Bacillus organisms are starch attackers. Sulfur and iron bacteria are predominant in wastes rich in respective compounds.

C Actinomyces, Bacillus spp., Aerobacter spp., and nitrogen-fixation bacteria are primarily soil dwellers and are almost always present in any type of wastes in small numbers.

D Parasitic and pathogenic bacteria, if present, are transient.

E In extended aeration process with high dissolved oxygen, predominant species are limited to pseudomonads, Zoogloea ramigera, and Sphaerotilus.

III PROTOZOA

A Classification

1 Single-cell animals in the phylum Protozoa in the animal kingdom.

or

2 A separate kingdom, **Protista**, to include protozoa, algae, fungi, and bacteria.

a Mastigophora (flagellates) - only the subclass Zoomastigina (non-pigmented) included; four orders:

1) Rhizomastigina - amoeba-flagellates with 1 or more flagella; examples: Mastigamoeba Actinomonas, Rhizomastix

2) Protomonadina - with 1 or 2 flagella; comprising most of the free-living forms; examples: Peranema, Bodo, Monas, Pleuromonas

3) Polymastigina - with 3-8 flagella; mostly parasitic in gut of man and animals

4) Hypermastigina - with numerous flagella; all parasitic in insect intestine

b Ciliophora or Infusoria (ciliates) - largest class of protozoa; no pigmented members; most important group of protozoa in waste treatment; 2 subclasses:

1) Ciliata - cilia present during the the entire trophic life; comprising most of the common ciliates; examples: Paramecium, Colpidium, Colpoda, Euplotes, Stylonychia, Vorticella, Opercularia, Epistylis, Carchesium

2) Suctoria - cilia present while young and tentacles during trophic life

c Sarcodina (amoebae) - pseudopodia (false feet) for locomotion and food-capturing; cell without cell-wall; some with test or shell; 2 subclasses:

1) Rhizopoda - pseudopodia without axial filaments; 5 orders:

a) Proteomyxa - with radiating pseudopodia; no test or shell

b) Mycetazoa (slime-molds) forming plasmodium; resembling fungi in sporangium formation.

c) Amoebina - true amoeba; pseudopodia in the form of lobopodia; no test or shell; cyst formation frequent; a few capable of flagellate transformation; examples: Naegleria, Amoeba, Hartmannella, Endamoeba

d) Testacea - amoeba with single test or shell; examples: Arcella, Difflugia

e) Foraminifera - large amoeba with calcareous shell; all marine forms

2) Actinopoda - with spinous pseudopodia; 2 orders:

a) Heliozoa - without central capsule, usually spherical in form with many radiating axopodia; examples: Actinosphaerium, Actinophrys

b) Radiolaria - pelagic in various oceans

d Sporozoa - no organ of locomotion; all parasitic (Plasmodium, Coccidia)

B General Morphology

1 Zoomastigina:

With the exception of Rhizomastigina which is amoeboid, the body has definite shape (oval, leaf-like, pear-like, etc.); most free-living forms with 1-2 flagella, some with 3 or more flagella; few forming colonies; cytostome present in many for feeding on bacteria; relatively small size (15-40 μ)

2 Ciliophora:

Most highly developed protozoa; with few exceptions, a macro- and a micronucleus; adoral zone, mouth, oral groove, usually present in swimming and crawling forms; stalked form with conspicuous ciliation of a disc-like anterior region and little or no body cilia; cyst formed in most species

3 Sarcodina:

Cytoplasmic membrane but not cell-wall; cytoplasm with distinct ectoplasm and endoplasm in many common spp.; nucleus with large nucleolus in most of the free-living forms; some with the body enclosed in a test or shell and moving by protruding pseudopodia outside of the enclosure through an opening; few capable of temporary transformation into flagellate; fresh-water actinopods usually spherical with many radiating axopodia; some Testacea spp. containing symbiotic algae - mistaken for pigmented amoebae; cysts with single or double wall and 1-2 nuclei, parasitic amoebae forming cysts with 4 or more nuclei

C General Physiology

1 Zoomastigina

Free-living forms normally holozoic; food supply mostly bacteria; relatively aerobic, therefore, among the first to disappear in anaerobic conditions; reproduction by simple fission and occasionally by budding.

2 Ciliophora:

Holozoic; true ciliates concentrating food particles, i.e., bacteria, by ciliary movement around the mouth-part; suctoria sucking through tentacles; bacteria, small algae and protozoa constituting main food under normal conditions; not as aerobic as flagellates - a few surviving under highly anaerobic conditions, such as Metopus; reproducing by simple fission, conjugation, or encystation.

3 Sarcodina:

Mostly holozoic; feeding through engulfing by pseudopodia; food supply of small amoebae mostly bacteria; large amoebae engulfing larger organisms; shelled amoebae, i.e., Arcella, feeding on a variety of organisms or saprozoic; reproduction by simple fission and encystation.

IV NEMATODA

A Classification

1 All in the phylum Nemata (nonsegmented round worms); 2 subphyla:

Secernentea (phasmids) 6 orders: Tylenchida (spear in mouth), Rhabditida (rhabditoid eosophagus), Strongylida (parasitic), Ascaridida (parasitic), Spirurida (parasitic), and Camallanida (parasitic); with the exception of tylenchids, all with papillae on male tail

Adenophora (aphasmids) 5 orders: Dorylaimida (spear in mouth), Chromodorida, Monhysterida, Enoplida, and Diocytophymatida; no papillae on male tail; no excretary canal

2 Nematodes encountered in polluted water and in sewage treatment mostly belonging to order Rhabditida and few in orders Dorylaimida and Tylenchida; those in Rhabditida being bacteria-feeders and those in the latter two, feeding on algae and other zoomicrobes; examples of rhabditids: Rhabditis, Diplogaster, Diplogasteroides, Monochoides, Cephalobus, Cylindrocorpus, Turbatrix; examples of the other two: Dorylaimus, Aphelenchoides

B General Morphology

Round, slender, nonsegmented (some with markings on outside); most of the free-living forms microscopic in size although dorylaimids up to several mm in length; sex separated but some parthenogenetic complete alimentray tract with elaborate mouth parts with or without spear (or stylet); no circulatory or respiratory system

C General Physiology

Most sewage treatment plant dwellers feeding on bacteria; others preying on protozoa, small nematodes, rotifers, etc.; clean water species vegetarians; DO diffused through cuticle; rhabditids tolerating lower DO than clean water spp; reproduction - eggs - larvae 4 molts) - adults

V ROTIFERS

A Classification:

1 Classified either as a class of the phylum Aschelminthes (various forms of worms) or as a separate phylum (Rotifera); commonly called wheel animalcules, on account of circular appearing movement of cilia around head (corona); corona contracted when crawling or swimming and expanded when attached to catch food.

2 Of the 3 classes, 2 (Seisonidea and Bdelloidea) grouped by some authors under Digononta (2 ovaries) and the other being Monogononta (1 ovary); Seisonidea containing mostly marine forms.

3 Class Bdelloidea containing 1 order (Bdelloida) with 4 families, Philodinedae being the most important.

4 Class Monogononta comprising 3 orders: Ploima with 14 families, Flosculariaceae with 4 families, and Collothecaceae with 1 family; most important genera included in the order Ploima (i.e., Brachionus, Keratella, Monostyla, Trichocerca, Asplanchna, Polyarthra, Synchaeta, Microcodon); common genera under the order Flosculariaceae: Floscularia, Limnias, Conochilus, and Atrochus.

5 Unfortunately orders and families of rotifers based on character of corona and trophi (chewing organ), which are difficult to study, esp. the latter; the foot and cuticle much easier to study.

B General Morphology and Physiology

1 Body weakly differentiated into head, neck, trunk, and foot, separated by folds; in some, these regions are merely gradual changes in diameter of body and without a separate neck; segmentation external only.

2 Head with corona, dosal antenna, and ventral mouth; mastax, a chewing organ, located in head and neck, connected to mouth anteriorly by a ciliated gullet and posteriorly to a large stomach occupying much of the trunk.

3 Common rotifers reproducing parthenogenetically by diploid eggs; eggs laid in water, cemented to plants, or carried on femals until hatching.

4 Foot, a prolongation of body, usually with 2 toes; some with one toe; some with one toe and an extra toe-like structure (dorsal spur).

5 Some, like Philodina, concentrating bacteria and other microbes and minute particulate organic matter by corona; larger microbes chewed by mastax; some such as Monostyla feeding on clumped matter, such as bacterial growth, fungal masses, etc. at bottom; virus generally not ingested - apparently undetected by cilia.

6 DO requirement somewhat similar to protozoa; some disappearing under reduced DO, others, like Philodina, surviving at as little as 2 ppm DO.

VI SANITARY SIGNIFICANCE

A Pollution tolerant and pollution nontolerant species - hard to differentiate - requiring specialist training in protozoa, nematodes, and rotifers.

B Significant quantitative difference in clean and polluted waters - clean waters containing large variety of genera and species but quite low in densities.

C Aerobic sewage treatment processes (trickling filters and activated sludge processes, even primary settling) ideal breeding grounds for those that feed on bacteria, fungi, and minute protozoa and present in very large numbers; effluents from such processes carrying large numbers of these zoomicrobes; natural waters receiving such effluents showing significant increase in all 3 categories.

D Possible Pathogen Carriers

1 Amoebae and nematodes grown on pathogenic enteric bacteria in lab; none alive in amoebic cysts; very few alive in nematodes after 2 days after ingestion; virus demonstrated in nematodes only when very high virus concentrations present; some free-living amoebae parasitizing humans.

2 Swimming ciliates and some rotifers (concentrating food by corona) ingesting large numbers of pathogenic enertic bacteria, but digestion rapid; no evidence of concentrating virus; crawling ciliates and flagellates feeding on clumped organisms.

3 Nematodes concentrated from sewage effluent in Cincinnati area showing live E. coli and streptococci, but no human **enteric** pathogens.

VII EXAMINATION OF SEWAGE TREATMENT EFFLUENT, AND SLUDGE FOR MICROBES

A Bacteria - Not Included

B Zoomicrobes -

The 12th edition of the Standard Methods (1965) has a part on Biologic Examination of Water, Wastewater, Sludge, and Bottom Materials, in which the sludge of sewage treatment is discussed, but very briefly. Much of the materials are concerned with sediment at bottom of natural bodies of water. Chang described a method for examination of water for nematodes; but the method is not applicable to sewage treatment, sludge, or effluent.

1 Waste treatment - the method bound to be qualitative; material scraped from stones in trickling filters or the floc masses in activated sludge examined in slide-coverslip preparations for poor, moderate, or rich zoobiota; material relatively rich in zoobiota indicating satisfactory treatment process; protozoa, rotifers, and nematodes predominant, especially protozoa; bristle worms and watermites in smaller numbers; springtails and insect larvae present as grazing fauna on top of trickling filters.

2 Sludge - representative samples suspended in known quantities of dilution water and thoroughly shaken; filtered through bolting cloth or metal screen of comparable pore size to remove extraneous dead clumped matter;filtrate examined in Sedgewick Rafter (SR) counting cell for various zoomicrobes; fresh sludge desired or samples refrigerated.

3 Sewage effluent - samples "fixed" with formalin, merthiolate, or similar chemical not desirable for examination for zoomicrobes; 50-200 ml filtered through a 7- or 14-micron membrane and strained material washed with a few mls of dilution and examined in an SR cell for zoo-microbes quantitatively or qualitatively.

VIII USE OF ZOOMICROBES AS POLLUTION INDEX

A Idea not new, protozoa suggested long ago; many considered impractical because of the need of identifying pollution-intolerant and pollution-tolerant species - protozoologist required.

B Can use them on a quantitative basis - nematodes, rotifers, and nonpigmented protozoa present in small numbers in clean water. Numbers greatly increased when polluted with effluent from aerobic treatment plant or recovering from sewage pollution; no significant error introduced when clean-water members included in the enumeration if a suitable method of computing the pollution index developed.

C Most practical method involves the equation: (A + B)/A = Z.P.I., where A = number of *pigmented* protozoa, B = other zoomicrobes, in a unit volume of sample, and Z.P.I. = zoological pollution index. For relatively clean water, the value of Z.P.I. close to 1; the larger the value above 1, the greater the pollution by aerobic effluent, or sewage during recovery. This is based on the fact that pigmented protozoa are members of clean water micro-fauna (stabilization pond excluded).

IX CONTROL

A Chlorination of Effluent and Settling

B Prolongation of Detention Time of Effluent

C Modification of Waste Treatment

D Elimination of Slow Sand Filters in Nematode Control

X LIST OF COMMON ZOOLOGICAL ORGANISMS FOUND IN SEWAGE TREATMENT PROCESS - TRICKLING FILTERS AND ACTIVATED SLUDGE PROCESS

PROTOZOA

Sarcodina - Amoebae

- *Amoeba proteus*; *A radiosa*
- *Hartmanella* spp.
- *Arcella vulgaris*
- *Naegleria gruberi*
- *Actinophrys sol*

FLAGELLATA

- *Bodo caudatus*
- *Pleuromonas jaculans*
- *Oikomonas termo*
- *Cercomonas longicauda*
- *Peranema trichophorum*

Swimming type

Ciliophora:

- *Colpidium colpoda*
- *Colpoda cucullus*
- *Glaucoma*
- *Paramecium caudatum*; *P. bursaria*

Stalked type

- *Opercularia* spp. (short stalk dichotomous)
- *Vorticella* spp. (stalk single and contractile)
- *Epistylis plicatilis* (like *Opercularia* more colonial)
- *Carchesium* spp. (like *Vorticella* but colonial, both have spiral coiled stalk when contracted)

Crawling type

- *Euplotes* spp.
- *Stylonychia mylitus*
- *Urostyla* spp.
- *Oxytricha* spp.

NEMATODA

- *Diplogaster* spp.
- *Monochoides* spp.
- *Diplogasteroides* spp.
- *Rhabditis* spp.
- *Pelodera* spp.
- *Aphelenchoides* sp.
- *Dorylaimus* sp.

Cylindrocorpus sp.
Cephalobus sp.
Rhabdolaimus sp.
Monhystera sp.
Trilobus sp.

ROTATORIA

Diglena
Monstyla
Polyarthra
Philodina
Keratella
Brachionus

OLIGOCHAETA (bristle worms)

Aelosoma hemprichi (Aelosomatidae)
Aulophorus vagus (Naididae)
Tubifex tubifex (Tubificidae)
Pachydrilus lineatus (Enchytraeidae)

INSECT LARVAE

Metriocnemus ssp. (midge)
Orthocladius ssp. (midge)
Psychoda spp. (filter fly)

OTHER ARTHROPODA

Hydrochna sp. (Acarina, mite)
Platysieus tenuipes (Acarina, mite)
Hypogastrura (• Achorutes sub-viatica) viaticus (Collembola, Springtail)
Folsomia sp. (Collembola, Springtail)
Tomocerus sp. (Collembola, Springtail)

MOLLUSCA

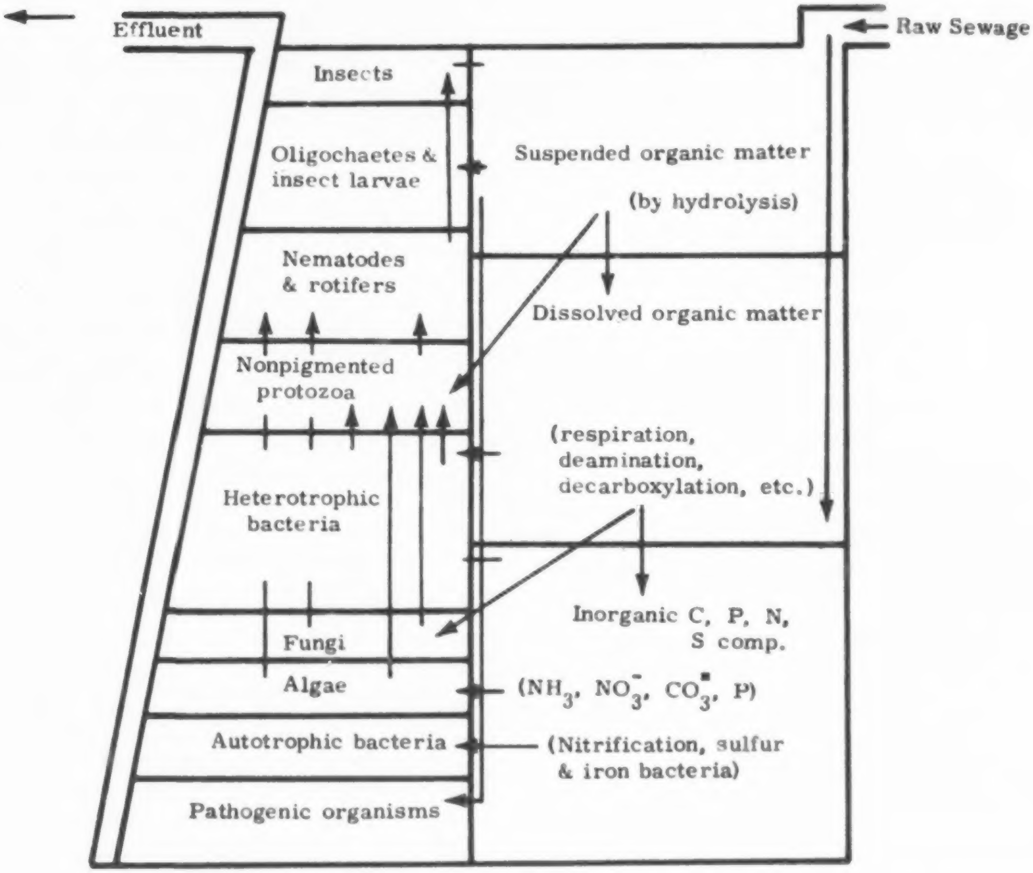
Lymnaea ssp. (pulmonate snail)
Physa sp. (pulmonate snail)

XI POPULATION DYNAMICS AND THE FOOD CHAIN IN AEROBIC SEWAGE TREATMENT PROCESSES (Figure 1 and 2)

A Aerobic bio-oxidation of waste materials comparable to a food chain through which the dead organic matter is converted to inorganic matter during the stabilization process, e.g., waste organic matter ⟶ bacterial phase ⟶ zoological phase ⟶ inorganic matter.

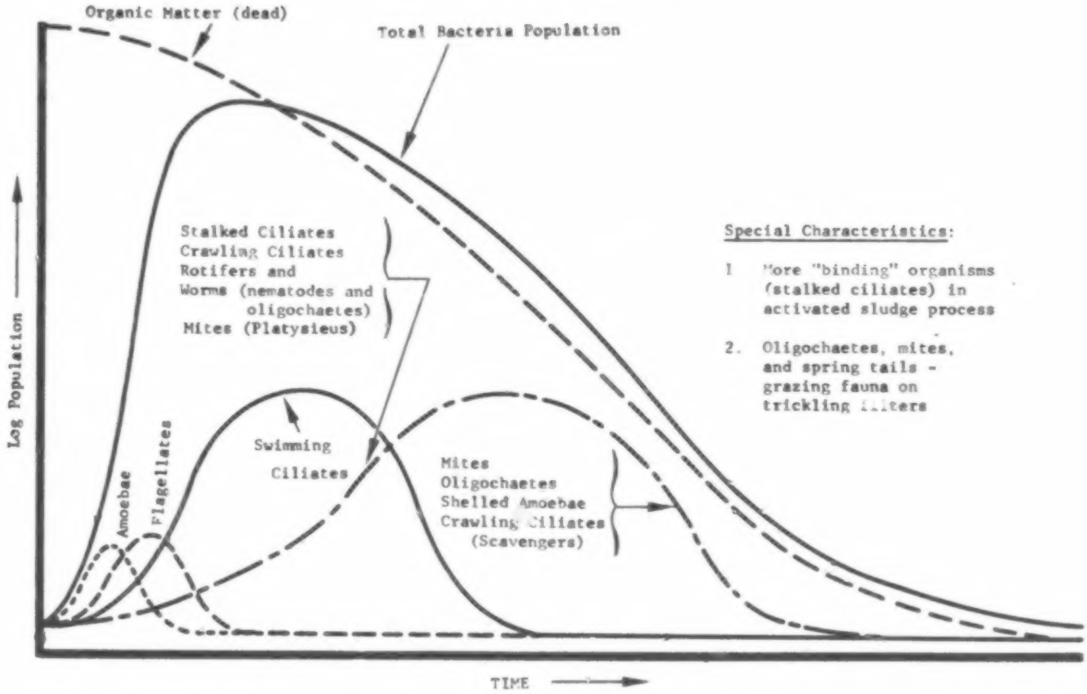
B Systematics, physiology and biochemistry involved in explaining the "chain reaction"; knowledge inadequate and fragmental; ecological study limited to principles governing the relationship of different groups of flora and fauna with each other and with the environment.

C With adequate DO supply, bacterial population increases rapidly in the presence of rich organic food; flagellates and amoebae, which feed on bacteria and other small particulate matter in clumped material (such as growth film and floc masses), first show increase in population size; as suspended bacterial population increases to a high level, swimming ciliates, which feed actively on the suspended bacteria, also increase; increased consumption of bacteria and reduced supply of dead organic matter results in decline in bacterial population, which, in turn, results in a decline in the swimming ciliate population; the presence of large populations of small protozoa (ciliates, flagellates, and amoebae) results in an increase in populations of rotifers, nematodes, stalked ciliates, and crawling ciliates, which feed on the small protozoa and bacteria that are lodged in clumped masses; eventually, scavengers, such as mites, shelled amoebae, certain nematodes, and bristle worms become predominant, and bacteria and small protozoa populations drop to the precycle level; rotifers that can concentrate bacteria in suspension, (such as Rotifer and Philodina, and nematodes), which have long surviving time, may remain for a long time; these zoomicrobes appear in the effluent in proportion to their respective population during treatment - nematodes, rotifers, ciliates predominant with small numbers of flagellates and amoebae; bristle worms unpredictable; mites few.


Effluent
Raw Sewage
Insects
Oligochaetes & insect larvae
Nematodes & rotifers
Nonpigmented protozoa
Heterotrophic bacteria
Fungi
Algae
Autotrophic bacteria
Pathogenic organisms
Suspended organic matter
(by hydrolysis)
Dissolved organic matter
(respiration, deamination, decarboxylation, etc.)
Inorganic C, P, N, S comp.
(NH3, NO3-, CO3=, P)
(Nitrification, sulfur & iron bacteria)

Food Chain in Aerobic Sewage Treatment Processes

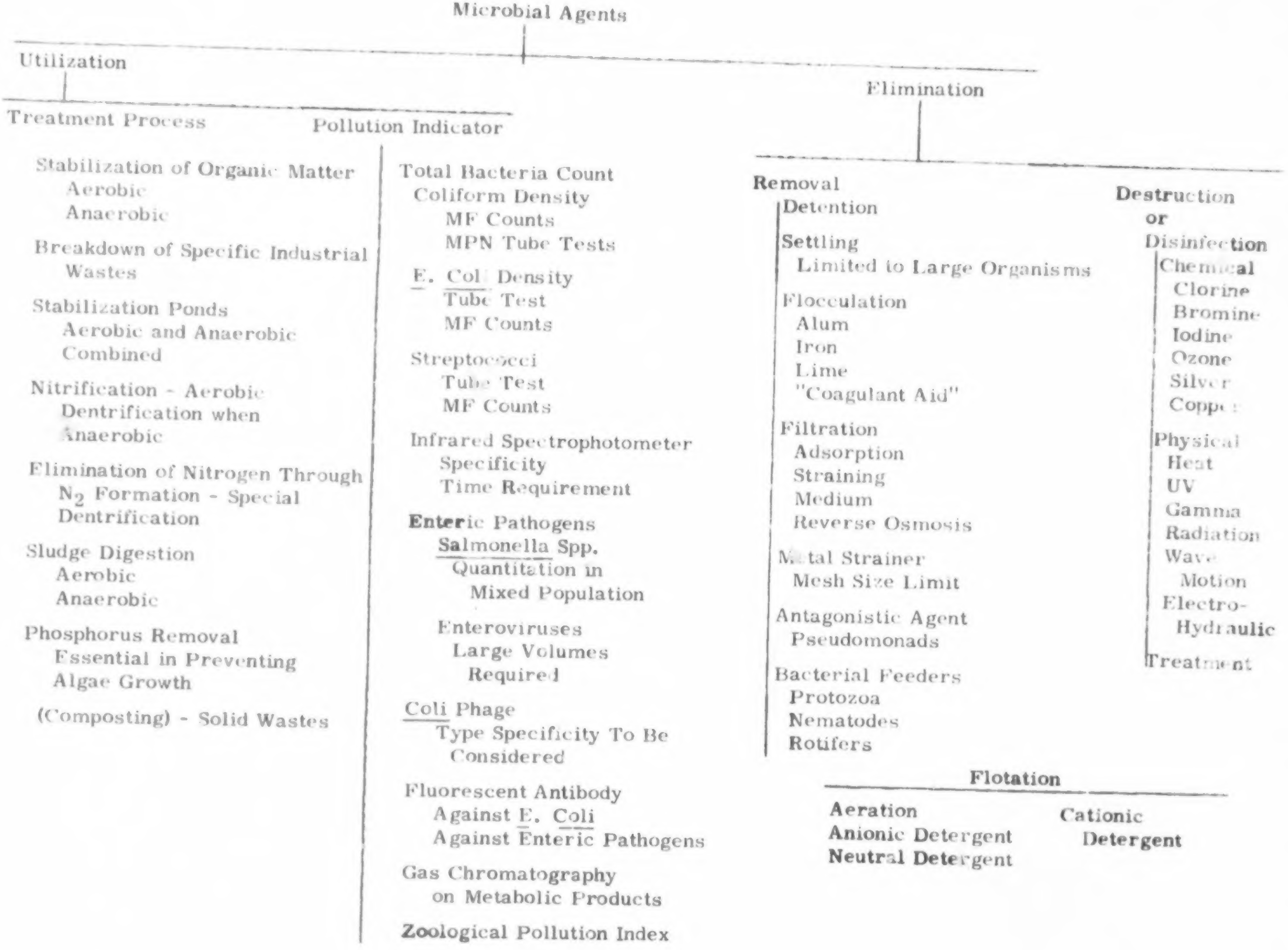
Figure 1.



Population dynamics in Aerobic Sewage Treatment Process

Figure 2.

D Since sewage effluent from aerobic treatment processes are rich in nonpigmented zoomicrobes, discharge of effluent into natural causes great increase in their members; unpolluted waters usually have a much higher algae-to-nonpigmented-zoomicrobes ratio. The great increase in the latter in water resulted from effluent pollution is likely to change this ratio, thus giving the basis for the Z.P.I. This analysis is not applicable to stabilization ponds due to the large algal population present in their effluents.



Microbial Agents

- Utilization
  - Treatment Process
    - Stabilization of Organic Matter
      - Aerobic
      - Anaerobic
    - Breakdown of Specific Industrial Wastes
    - Stabilization Ponds
      - Aerobic and Anaerobic Combined
    - Nitrification - Aerobic
      - Dentrification when Anaerobic
    - Elimination of Nitrogen Through
      - N_2 Formation - Special Dentrification
    - Sludge Digestion
      - Aerobic
      - Anaerobic
    - Phosphorus Removal
      - Essential in Preventing Algae Growth
    - (Composting) - Solid Wastes
  - Pollution Indicator
    - Total Bacteria Count
      - Coliform Density
        - MF Counts
        - MPN Tube Tests
    - E. Coli Density
      - Tube Test
      - MF Counts
    - Streptococci
      - Tube Test
      - MF Counts
    - Infrared Spectrophotometer
      - Specificity
      - Time Requirement
    - **Enteric** Pathogens
      - Salmonella Spp.
        - Quantitation in Mixed Population
      - Enteroviruses
        - Large Volumes Required
    - Coli Phage
      - Type Specificity To Be Considered
    - Fluorescent Antibody
      - Against E. Coli
      - Against Enteric Pathogens
    - Gas Chromatography
      - on Metabolic Products
    - **Zoological** Pollution Index
- Elimination
  - **Removal**
    - Detention
    - **Settling**
      - Limited to Large Organisms
    - Flocculation
      - Alum
      - Iron
      - Lime
      - "Coagulant Aid"
    - Filtration
      - Adsorption
      - Straining
      - Medium
      - Reverse Osmosis
    - Metal Strainer
      - Mesh Size Limit
    - Antagonistic Agent
      - Pseudomonads
    - Bacterial Feeders
      - Protozoa
      - Nematodes
      - Rotifers
  - **Destruction or Disinfection**
    - Chemical
      - Clorine
      - Bromine
      - Iodine
      - Ozone
      - Silver
      - Copper
    - Physical
      - Heat
      - UV
      - Gamma Radiation
      - Wave Motion
      - Electro-Hydraulic
    - Treatment
  - **Flotation**
    - **Aeration**
    - **Anionic Detergent**
    - **Neutral Detergent**
    - **Cationic Detergent**

Figure 3

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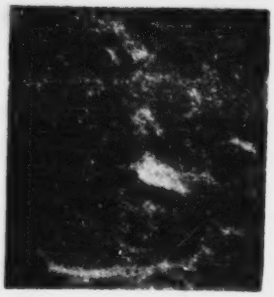
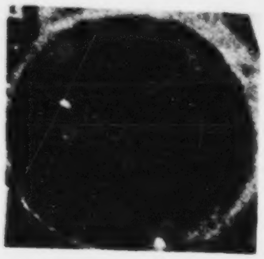
This outline was prepared by S. L. Chang, M. D., Chief, Etiology, Division of Water Supply Programs Division, WPO, EPA. Revised by R. M. Sinclair, Aquatic Biologist, National Training Center, DTTB, MDS, WPO, EPA, Cincinnati, OH 45268.

a. Peranema trichoporum, 25u

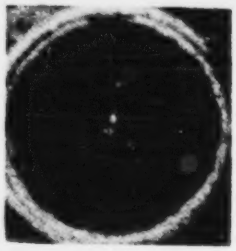


b. Naegleria gruberi amoeba stage, 18u

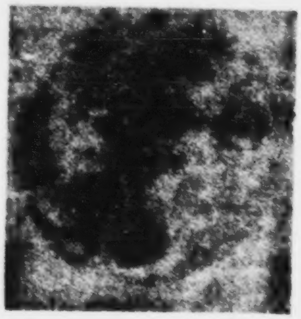
c. N. gruberi flagellate stage



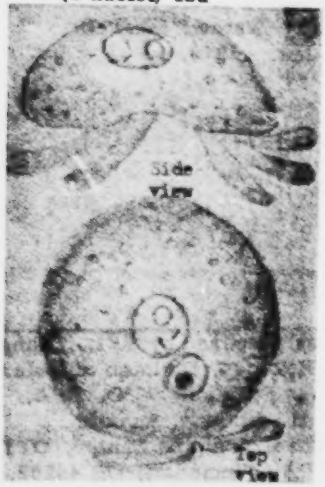
d. N. gruberi, cyst (2 nuclei) 12u



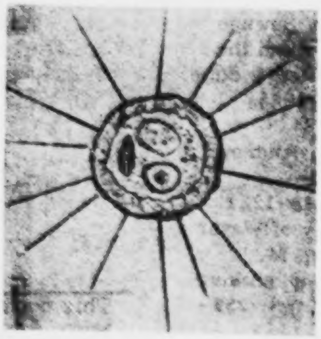
e. N. gruberi, cyst (1 nucleus)



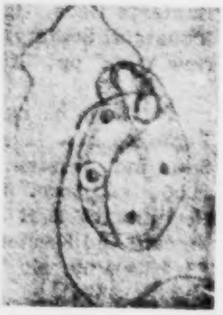
f. Endamoeba histolytica cyst (4 nuclei) 16u



g. Arcella vulgaris 40u



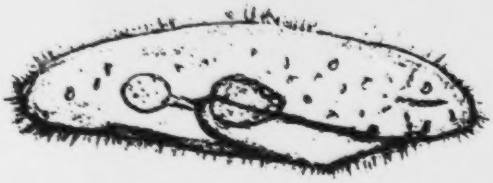
h. Actinosphaerium sp. 200-300u (with a navicula inside)



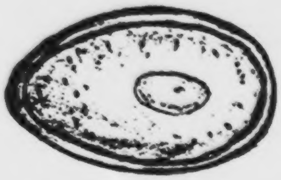
i. Bodo caudatu 10-20u

Fig. 1

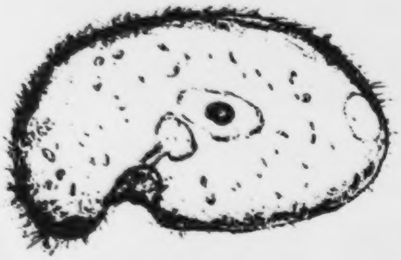
S. L. Chang, 1963



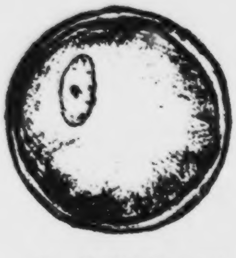
a. **Paramecium caudatum**
200 - 260u



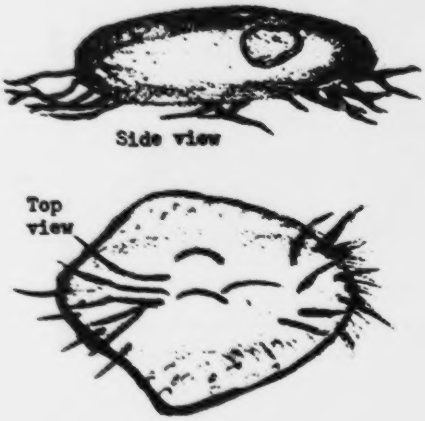
b. **P. caudatum**
cyst



c. **Colpoda** sp. 20-120u



d. **Colpoda** cyst

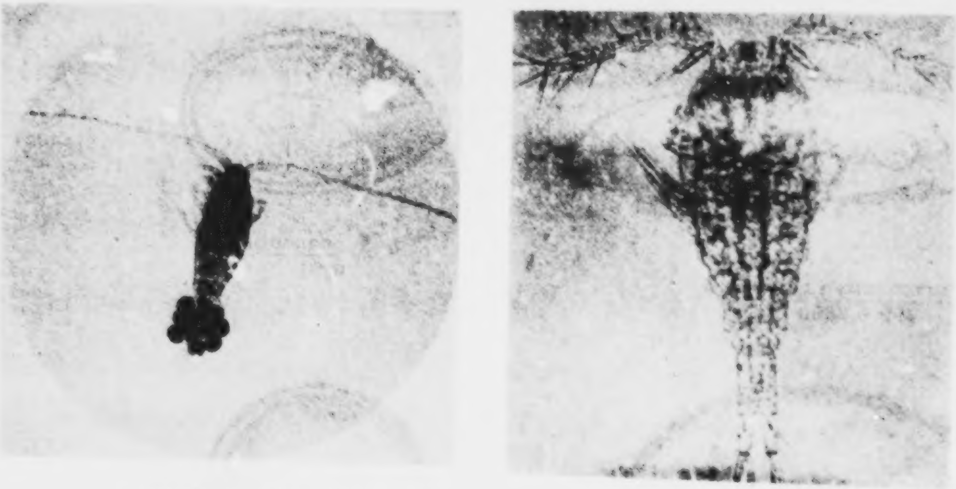


e. **Euplotes carcinatus**
70u

f. **Vorticella** 35-157u

Fig. 2

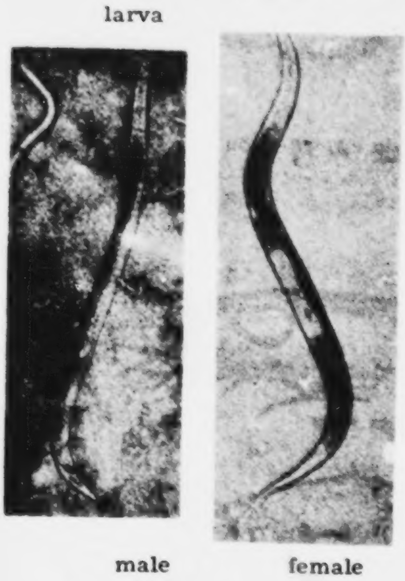
S. L. Chang, 1963



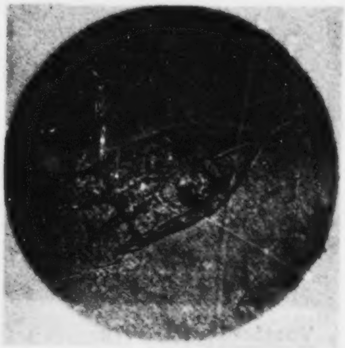
a. Diaptomus sp. 2 mm.
(2 egg sacs

b. Cyclops sp. 2 mm.

c. Philodina sp. 45u



e. Diplogaster nudicapitatus
about 1 mm.

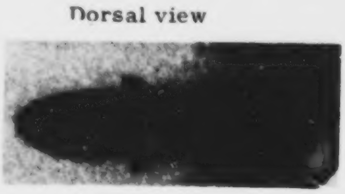


d. Anurea cochlearis 125u

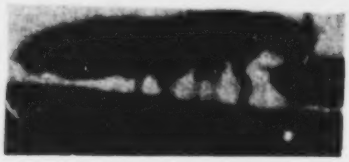
Fig. 3

S. L. Chang, 1963

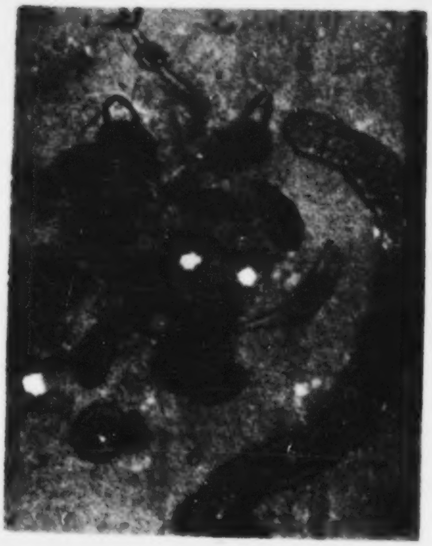
a. Hydrochna sp. (water mite) (50X)



b. Folsomia fimetaria (50X)



c. F. fimetaria (side view)

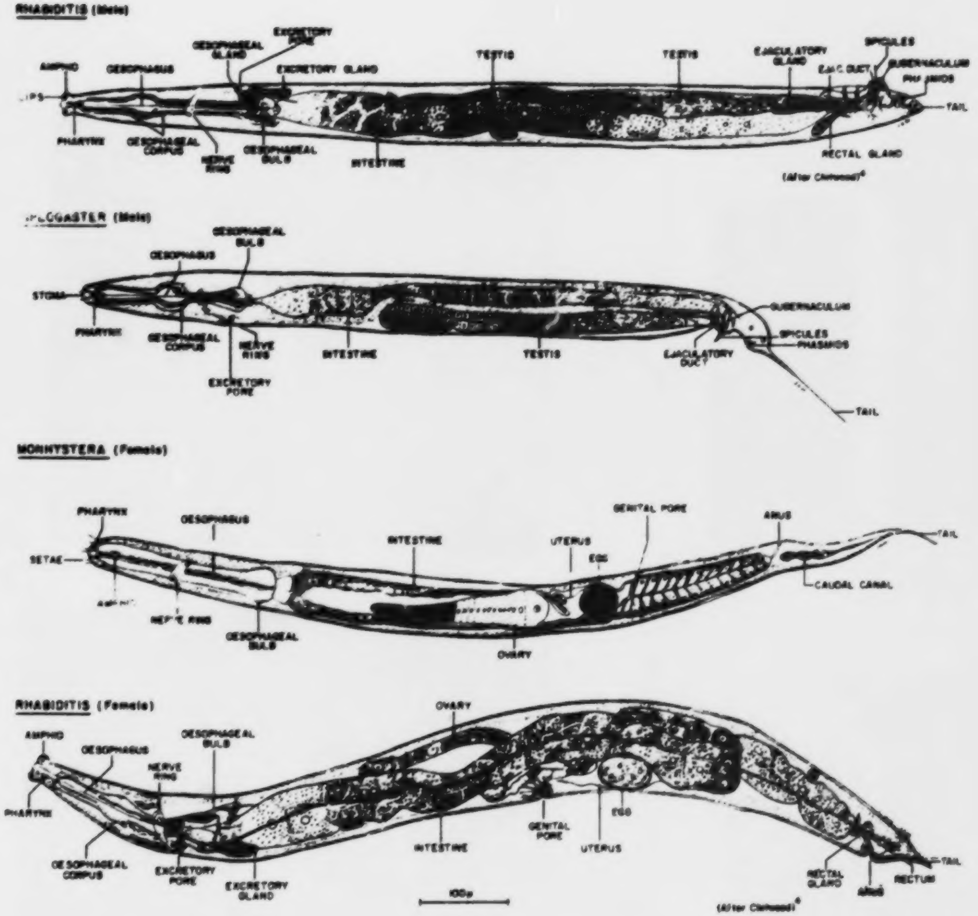


d. Typical zoological organisms found in growth mass in Trickling filters (50X)

e. Typical zoological organisms found in floc masses in activated sludge process (50X)

Fig. 4

S. L. Chang, 1963


RHABIDITIS (Male)
LIPS
AMPHID
OESOPHAGUS
PHARYNX
OESOPHAGEAL CORPUS
NERVE RING
OESOPHAGEAL GLAND
EXCRETORY PORE
EXCRETORY GLAND
OESOPHAGEAL BULB
INTESTINE
TESTIS
TESTIS
EJACULATORY GLAND
EJAC. DUCT
SPICULES
GUBERNACULUM
PHASMIDS
TAIL
RECTAL GLAND
(After Chitwood)6
LOGASTER (Male)
STOMA
PHARYNX
OESOPHAGUS
OESOPHAGEAL BULB
OESOPHAGEAL CORPUS
NERVE RING
EXCRETORY PORE
INTESTINE
TESTIS
EJACULATORY DUCT
GUBERNACULUM
SPICULES
PHASMIDS
TAIL
MONHYSTERA (Female)
PHARYNX
SETAE
AMPHID
OESOPHAGUS
NERVE RING
OESOPHAGEAL BULB
INTESTINE
OVARY
UTERUS
EGG
GENITAL PORE
ANUS
TAIL
CAUDAL CANAL
RHABIDITIS (Female)
AMPHID
PHARYNX
OESOPHAGUS
NERVE RING
OESOPHAGEAL BULB
OESOPHAGEAL CORPUS
EXCRETORY PORE
EXCRETORY GLAND
OVARY
INTESTINE
GENITAL PORE
UTERUS
EGG
RECTAL GLAND
ANUS
RECTUM
TAIL
100μ
(After Chitwood)6

Free Living Nematodes

(Nemathelminthes)

BIOLOGY OF ZOOPLANKTON COMMUNITIES

I CLASSIFICATION

A The planktonic community is composed of organisms that are relatively independent of the bottom to complete their life history. They inhabit the open water of lakes (pelagic zone). Some species have inactive or resting stages that lie on the bottom and carry the species through periods of stress; e.g., winter. A few burrow in the mud and enter the pelagic zone at night, but most live in the open water all the time that the species is present in an active form.

B Compared to the bottom fauna and flora, the plankton consists of relatively few kinds of organisms that are consistently and abundantly present. Two major categories are often called phytoplankton (plants) and zooplankton (animals), but this is based on an outmoded classification of living things. The modern tendency is to identify groupings according to their function in the ecosystem: Primary producers (photosynthetic organisms), consumers (zooplankton), and decomposers (heterotrophic bacteria and fungi).

C The primary difference then is nutritional; phytoplankton use inorganic nutrient elements and solar radiation. Zooplankton feed on particles, much of which can be phytoplankton cells, but can be bacteria or particles of dead organisms (detritus) originating in the plankton, the shore region, or the land surrounding the lake.

D The swimming powers of planktonic organisms is so limited that their horizontal distribution is determined mostly by movements of water. Some of the animals are able to swim fast enough that they can migrate vertically tens of meters each day, but they are capable of little horizontal navigation. At most, some species of crustaceans show a general avoidance of the shore areas during calm weather when the water is moving more slowly than the animals can swim. By definition, animals that are able to control their horizontal location are nekton, not plankton.

E In this presentation, a minimum of classification and taxonomy is used, but it should be realized that each group is typified by adaptations of structure on physiology that are related to the planktonic mode of existence. These adaptations are reflected in the classification.

II FRESHWATER ZOOPLANKTON

A The freshwater zooplankton is dominated by representatives of three groups of animals, two of them crustaceans: Copepoda, Cladocera, Rotifera. All have feeding mechanisms that permit a high degree of selectivity of food, and two can produce resting eggs that can withstand severe environmental conditions. In general the food of usual zooplankton populations ranges from bacteria and small algae to small animals.

B The Copepoda reproduce by a normal biparental process, and the females lay fertilized eggs in groups which are carried around in sacs until they hatch. The immature animals go through an elaborate development with many stages. The later stages have mouthparts that permit them to collect particles. In many cases, these are in the form of combs which remove small particles by a sort of filtration process. In others, they are modified to form grasping organs by which small animals or large algae are captured individually.

C The Cladocera (represented by *Daphnia*) reproduce much of the time by parthenogenesis, so that only females are present. Eggs are held by the mother in a brood chamber until the young are developed far enough to fend for themselves. The newborn animals look like miniature adults, and do not go through an elaborate series of developmental stages in the water as do the copepods. *Daphnia* has comb-formed filtering structures on some of its legs that act as filters.

D Under some environmental conditions the development of eggs is affected and males are produced. Fertilized eggs are produced that can resist freezing and drying, and these carry the population through unsatisfactory conditions.

E The Rotifera are small animals with a ciliated area on the head which creates currents used both for locomotion and for bringing food particles to the mouth. They too reproduce by parthenogenesis during much of the year, but production of males results in fertilized, resistant resting eggs. Most rotifers lay eggs one at a time and carry them until they hatch.

III ZOOPLANKTON POPULATION DYNAMICS

A In general, zooplankton populations are at a minimum in the cold seasons, although some species flourish in cold water. Species with similar food requirements seem to reproduce at different times of the year or are segregated in different layers of lakes.

B There is no single, simple measurement of activity for the zooplankton as a whole that can be used as an index of production as can the uptake of radioactive carbon for the phytoplankton. However, it is possible to find the rate of reproduction of the species that carry their eggs. The basis of the method is that the number of eggs in a sample taken at a given time represents the number of animals that will be added to the population during an interval that is equal to the length of time it takes the eggs to develop. Thus the potential growth rate of the populations can be determined. The actual growth rate, determined by successive samplings and counting, is less than the potential, and the difference is a measure of the death rate.

C Such measurements of birth and death rates permits a more penetrating analysis to be made of the causes of population change than if data were available for population size alone.

D Following is an indication of the major environmental factors in the control of zooplankton.

1 Temperature has an obvious effect in its general control of rates. In addition, the production and hatching of resting eggs may be affected.

2 Inorganic materials

Freshwater lakes vary in the content of dissolved solids according to the geological situation. The total salinity and proportion of different dissolved materials in water can affect the population. Some species are limited to soft water, others to saline waters, as the brine shrimp. The maximum population size developed may be related to salinity, but this is probably an indirect effect working through the abundance of nutrients and production of food.

3 Food supply

Very strong correlations have been found between reproduction and food supply as measured by abundance of phytoplankton. The rate of food supply can affect almost all aspects of population biology including rate of individual growth, time of maturity, rate of reproduction and length of life.

4 Apparently in freshwater, dissolved organic materials are of little nutritional significance, although some species can be kept if the concentration of dissolved material is high enough. Some species require definite vitamins in the food.

5 Effect of predation on populations

The kind, quantity and relative proportions of species strongly affected by grazing by vertebrate and invertebrate predators. The death rate of Daphnia is correlated with the abundance of a predator. Planktivorous fish (alewives) selectively feed on larger species, so a lake with alewives is dominated by the smaller species of crustaceans and large ones are scarce or absent.

6 Other aspects of zooplankton

Many species migrate vertically considerable distances each day. Typically, migrating species spend the daylight hours deep in the lake and rise toward the surface in late afternoon and early evening.

Some species go through a seasonal change of form (cyclomorphosis) which is not fully understood. It may have an effect in reducing predation.

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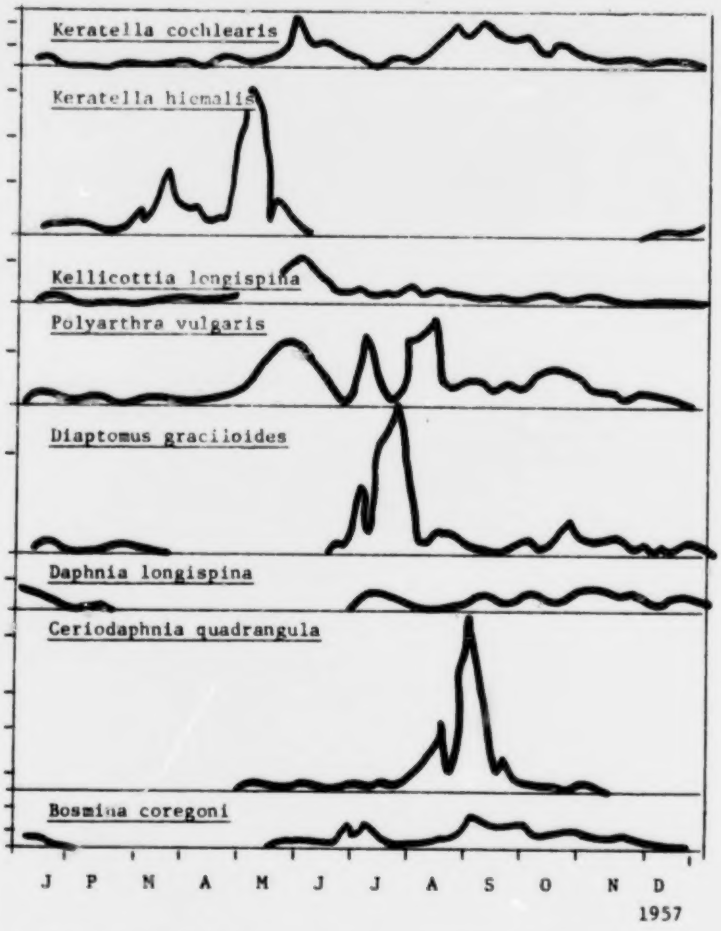
This outline was prepared by W. T. Edmondson, Professor of Zoology, University of Washington, Seattle, Washington.

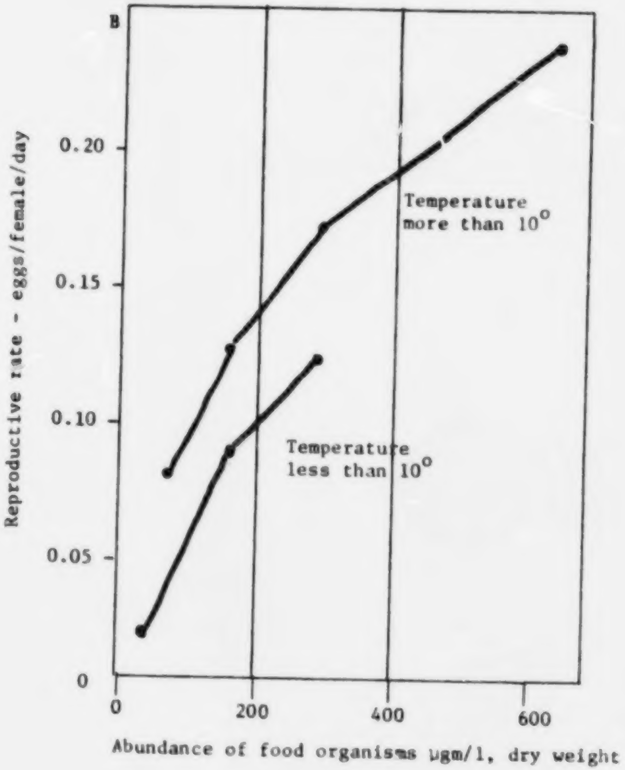
FIGURE 1 SEASONAL CHANGES OF ZOOPLANKTON IN LAKE ERKEN, SWEDEN



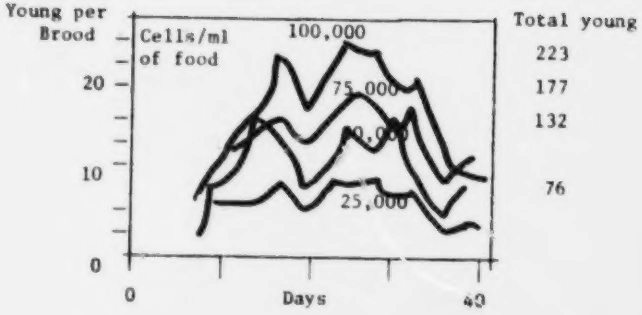
Each panel shows the abundance of a species of animal. Each mark on the vertical axis represents 10 individuals/liter. Nauwerck, A. 1963. Die Beziehungen zwischen Zooplankton und Phytoplankton im See Erken. Symbolae Botanicae Upsalienses, 17:1-163.

8-4

FIGURE 2 REPRODUCTIVE RATE OF ZOOPLANKTON AS A FUNCTION OF ABUNDANCE OF FOOD

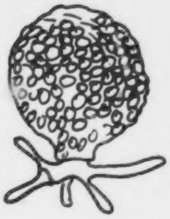


Mean rate of laying eggs by the planktonic rotifer Keratella cochlearis in natural populations as a function of abundance of food organisms and temperature. W. T. Edmonson. 1965. Reproductive rate of planktonic rotifers as related to food and temperature in nature. Ecol. Mmogr. 35: 61-111.



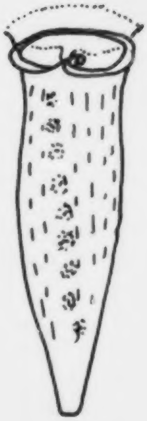
Number of young produced in each brood by Daphnia living in four different concentrations of food organisms, renewed daily. The total number produced during the life of a mother is shown by the numbers at the right. The Daphnia at the two lowest concentrations produced their first batch of eggs on the same day as the others, but the eggs degenerated, and the first viable eggs were released two days later. Richman, S. 1958. The transformation of energy by Daphnia pulex. Ecol. Monogr. 28: 273-291.

PROTOZOA

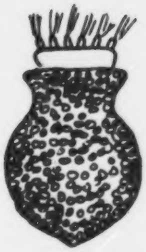


Difflugia

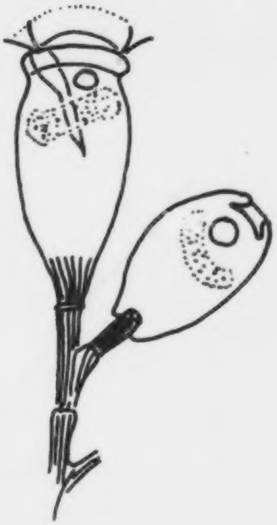
Amoebae



Stentor



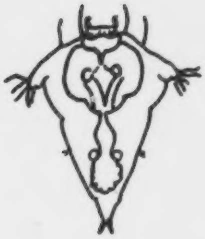
Codonella



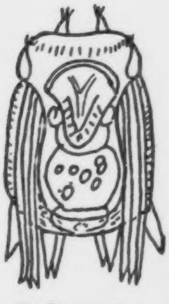
Epistylis

Ciliates

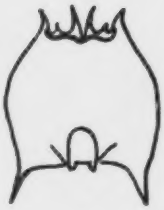
ROTIFERA



Synchaeta



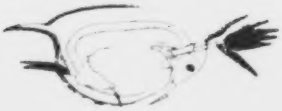
Polygarthra



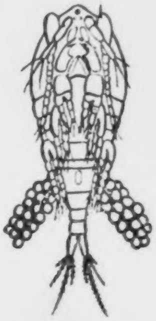
Brachionus

ARTHROPODA

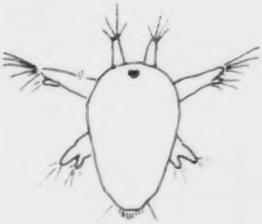
Crustacea



Cladocera



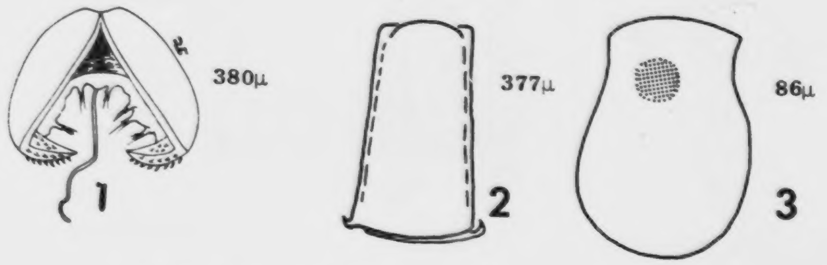
Copepoda



Nauplius larva of copepod

Insecta - Chaoborus

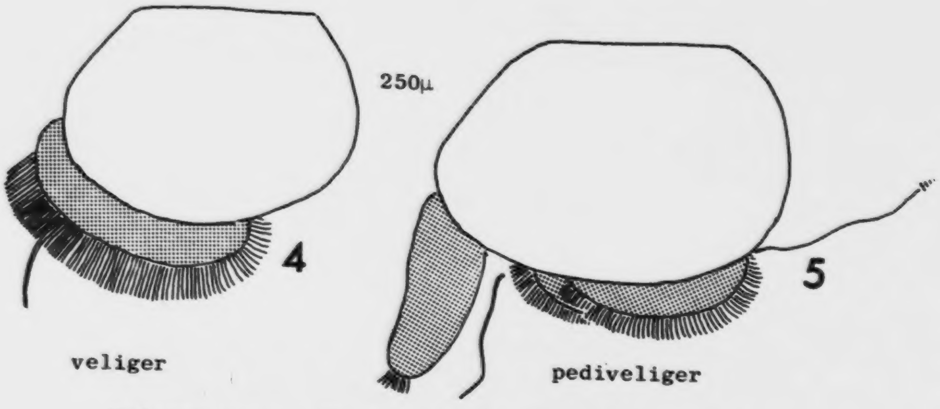
PLANKTONIC BIVALVE LARVAE



spined (fin attached)

simple (gill attached)

Glochidia (Unionidae) Fish Parasites
(1-3)



veliger

pediveliger

Veliger Larvae (Corbiculidae) Free Living Planktonic
(4-5)

Pediveliger attaches byssus lines)

MACRO INVERTEBRATES

I INTRODUCTION

Groups included are in general those which may be seen and recognized without the use of a microscope. For a more restricted definition in reference to bottom sampling, they are defined as those invertebrates retained on a No. 30 sieve (approx. 0.5 mm aperture).

II PHYLUM PORIFERA - Sponges

A Often encountered in the "pipe-moss" complex. Being true animals, they will grow in the dark and hence require only a water possessing adequate food materials.

B Freshwater sponges usually appear as brownish or greenish masses, (where containing zoochlorellae), irregular in shape, growing on twigs or solid surfaces. Erect or branching shapes sometimes found. Surface non-shiny, texture delicate. May form overgrowths on irrigation canal walls.

C Microscopic structure characterized by silica "spicules" and reproductive structures known as "gemmules".

1 Spicules are in general long slender crystals. In some, the ends are simple or pointed, in others expanded into various shapes.

2 Spicules of various types are interwoven like the twigs of a bird nest to form the skeleton of the sponge. The nature of the soft living tissue cells indicate a probable evolutionary origin of the sponge from flagellated and amoeboid protozoa.

3 Gemmules are little bundles of tissue cells, protected by spicules, which can resist unfavorable conditions. They are often found scattered throughout the mass of a sponge. These are analagous to turions in some aquatic plants and statoblasts in bryozoans.

III PHYLUM COELENTERATA - The Jellyfishes, Corals, and Hydras

A This group is of relatively little importance in fresh water, although quite prominent in the ocean.

B The freshwater hydra is a typical and simple coelenterate. Its structure is essentially a long slender sac, two layers thick, with tentacles extending out from around the open end or mouth.

1 Fully extended individuals may measure a half inch or more.

2 Generally an indicator of clean water. Rarely a nuisance.

C Craspedacusta, a freshwater jellyfish occasionally appears in great numbers in lakes and reservoirs in late summer. No particular nuisance conditions are known to result, although tastes and odors might be expected if sufficient numbers were taken into a water treatment plant. No reasons are known for their sporadic appearances, no public health significance is known, and no control measures can be recommended.

D Cordylophora, a colonial hydroid is a typical attached organism in large rivers, lakes, and reservoirs.

IV PHYLUM PLATYHELMINTHES - Tapeworms, Flukes, and Planarias

A Tapeworms and flukes are serious human parasites in many parts of the world, but generally under good control in North America. Most of them have relatively complicated life histories involving one or more "intermediate" hosts and a "final" host.

B The human tapeworm Diphyllobothrium latum is a form of modest significance, endemic to our northern states.

  1 It is the largest of the human tapeworms.

  2 It is obtained by eating underdone fish of the pike family.

C Human fluke parasites have certain species of snails as intermediate hosts. Larval forms, cercariae released from snails penetrate human skin directly while the person is wading or bathing in infested waters.

  1 Although one or two species of snail in southern United States are thought to be capable of transmitting the human blood fluke, none are known to do so at the present time.

  2 Flukes also parasitize other animals than man. Occasionally the cercaria larvae of non-human parasites will be attracted to humans bathing in infested waters. They are able to enter the skin but cannot complete penetration, and so are trapped. The result is a rash, often quite painful, known as "swimmer's itch". This now occurs widely across the northern states and in many coastal waters. Control measures are directed at the elimination of species of snails.

D The Planarians (Class Turbellaria) are large enough to spot with the naked eye. They are useful field indicators of pollution, but shrivel up on preservation, and are seldom recognized in the laboratory.

V PHYLUM BRYOZOA - Moss Animals

A These are small, colonial, sessile animals, common in both marine and fresh waters. Their main significance is as contributors to the pipe-moss complex, and as indicators of the degree of pollution.

B Freshwater forms are usually either creeping brown moss-like forms that grow over the undersides of rocks or in pipes, or larger gelatinous masses growing on sticks and rocks in lakes and reservoirs.

  1 The closely adhering threads on rocks or pipes may range up to 1/16th of an inch in width. Microscopic examination reveals numerous raised openings from which when undisturbed, tiny fans of tentacles (the lophophore) are extended. Closely packed colonies may reach an inch in depth, and if adjacent colonies have come into contact, an indefinite area may be covered.

  2 Another type produces clear jelly-like masses of transparent or faintly tinted material, with minute, often colored, individuals (zooids) scattered over the surface. The animals are extremely timid and only with great care and patience can they be observed with the tentacles expanded. Colonies of some species are reported to approach six feet in length, but smaller forms are more common. Certain types of colonies can slowly change their position.

  3 Reproduction is by means of unique structure known as a "statoblast". This is a discoid or eleptical structure, often with anchor-shaped hooks, which can resist winter conditions and even drying. Statoblasts usually germinate in spring, colonies reach full development by late summer.

VI PHYLUM MOLLUSCA - Snails, Clams, also Oysters, Squids, Octopi

A Freshwater molluscs are in general animals with a soft body, encased in a calcareous shell which may be single (snails) or double (clams and mussels). Marine forms such as the squid, nautilus, octopus, slugs, and others, would require additional qualification.

B In the snail group (Class Gastropoda) the shell may be coiled in various ways, or a simple tent-shaped secretion on the animal's back. These animals possess a distinct head, with a pair of contractile tentacles, at the base of which are placed the eyes.

  1 The mouth is provided with a unique flexible rasp-like structure, the radula. Chitinous jaws too are usually present.

2 The two main groups in freshwater are the air breathers (Order Pulmonata) and the water breathers (Order Streptoneura). Since all Streptoneura have a peculiar chitinous or calcareous "trap door" called an operculum (used for closing the shell) they are also called the "operculate" snails (vs the "nonoperculate" Pulmonata).

3 Many snails are classed as "nuisance organisms".

a Snails are quick to take advantage of organic enrichment. As pollution eliminates predators, pulmonate snails (such as Physa, Lymnea) thrive. Trickling filters, polluted streams, and similar locations are often nearly choked with these organisms.

b Certain snails are also the intermediate host for certain fluke parasites as mentioned elsewhere, and hence may constitute an important link in the control of these parasites.

C The Bivalved Molluscs (Class Bivalvia) have the body protected by two symmetrical, opposing valves or shells, which are united above by a flexible elastic tissue called the "ligament," which is also secreted by the mantle.

1 They have no head. The foot is an axe-shaped mass of muscular tissue which may be extended and used to drag the animal ahead. The shell is secreted by two sheets of tissue called the mantle.

2 They feed by straining particles out of the water by means of two sets of lace-like gills (ctenidia). They are thus animated filters and when present in significant numbers may contribute to the reduction of turbidity with resulting solids accumulation.

3 Certain thick shelled forms such as the Unionidae formerly commercially harvested for use in making pearl buttons, are exported to Japan for production of nuclei for the cultured pearl industry.

4 Certain small types (family Sphaeriidae) such as Sphaerium the fingernail clam, have been shown to tolerate considerable organic pollution.

5 The Asian Clam, Corbicula. An exotic, intermediate insize between the above two families, is a serious pipe clogging organism. Unlike the endemic families it has planktonic larvae; hence, it's nuisance potential.

VII PHYLUM ANNELIDA - The segmented Worm: Earthworms, Sludgeworms, and Leeches (Sometimes regarded as separate phyla)

A Class Oligochaeta, the earthworm-sludgeworm group. Body clearly divided into segments. Bristle like "setae" or hairs present on most segments, are used in locomotion; in some species may be withdrawn beneath body surface.

1 Accurate identification requires simple clearing procedures with the specimen. Although these worms are hermaphroditic (having both sexes in the same individual), many of the smaller forms commonly reproduce by a type of a sexual budding which produces chains of two or more individuals.

2 Aquatic earthworms and sludgeworms, like their terrestrial counterparts, feed on the soil or mud in which they live, and contribute very significantly to its stabilization. Having hemoglobin in their blood, some of them can tolerate very low oxygen tensions. Like the snails mentioned above, they thus thrive in polluted conditions in the absence of predators (ex: Tubifex, Limnodrilus.) Smaller types (ex: Aelosoma, Chaetogaster) may abound in activated sludge.

B Class Hirudinea - leeches

1 These organisms are essentially ectoparasites of vertebrates, though they may also feed on smaller annelids, snails, insect larvae, and organic ooze. They are characterized by the possession of an anterior and posterior sucker

disc, and the absence of setae. Eyes if present, are located on the (smaller) anterior or oral sucker, although sensory cells are widely scattered over the general body surface.

2 They are not known to be the vectors of any human disease, although when present in numbers, their blood sucking habits give them a considerable nuisance value.

3 Their tolerance for sewage pollution is considerable and they are hence often present in great numbers in polluted streams.

VIII PHYLUM ARTHROPODA - The Jointed Animals

A Characterized in general by paired jointed legs on a body nearly always segmented, and a chitinous exoskeleton. Three of the major groups have freshwater representatives: The Crustacea, Arachnida, and Insecta. The Insecta will be treated in a separate section.

B Class Crustacea

1 Characterized by two pair of antennae, respiration by means of blood gills (or general body surface). The vast majority of crustacea are aquatic. Crabs and lobsters are well known marine examples, water fleas and copepods well known freshwater examples. No freshwater species approach the giant marine species for size where the king crab, for example, may have a leg spread of several feet.

2 A few specialized terms used frequently in connection with the Crustacea are defined below.

Head:	The anterior part of the body containing the mouth. Usually consists of two or more fused segments, each represented by a pair of specialized mouth-parts.
Thorax:	The major section of the body behind the head. Contains most of the body organs and usually the walking (or swimming) legs.
Abdomen:	The most posterior section of the body. Contains the anus and often gills. Is seldom involved in locomotion except in swimming forms.
Caphalothorax:	The fused head and thorax.
Carapace:	A fold of the body wall or shell which usually extends down over each side of the thorax. May cover the whole side or only the bases of the legs.
Antenna:	Sensory appendages or "feelers". Typically two in number in the Crustacea.
Biramous:	Two branched.

3 Subclass Branchipoda - phyllopods

These organisms have many pairs of flattened appendages serving for both locomotion and respiration.

The first three orders as listed below tend to inhabit temporary pools, and so are often good indicators of such water. Life histories may often be completed in 2-3 weeks. Occurrence is quite sporadic. Many of them are tolerant of highly saline or alkaline waters.

The Cladocera, the last order, is more of an inhabitant of permanent bodies of water. All are in general, plankton and detritus feeders, often tolerant of high organic content as long as aerobic conditions are maintained.

a Order Anostraca - fairy shrimps. Eleven to 17 pairs of thoracic appendages, elongate, cylindrical body without a carapace, eyes stalked.

Ex: Artemia (the brine shrimp), General size range 15-30 mm. extreme: 5-100 mm. Swim gracefully on their backs.

b Order Notostraca - tadpole shrimps. Forty - 60 pairs of thoracic appendages, body depressed and partly covered by a dorsal shield like carapace. Eyes sessile. Size up to 100 mm.

c Order Conchostraca - clam shrimps. Ten - 28 thoracic appendages. Body laterally compressed and completely enclosed in a bivalved carapace which is often relatively thin and marked by successive lines of growth. Generally favored by warmer water. Size: 4-16 mm.

d Order Cladocera - water fleas. Four - 6 pairs of thoracic appendages. Body laterally compressed, all except the the distinct head usually enclosed in a bivalved carapace. Second antenna is branched, and used for locomotion. Single compound eye. Size: 0.2-3.0 mm or more. Common genera include Daphnia and Bosmina.

1) This is a large and widely dispersed group, a common component of our plankton in nearly all types of water.

2) Generally parthenogenetic, until unfavorable conditions stimulate the production of males. Sexual eggs result which can withstand freezing and drying.

3) Species in general are very widely distributed.

4 Subclass Ostracoda - seed shrimps. Two or three pairs of thoracic appendages. Body laterally compressed, and entirely enclosed in a bivalve carapace. Freshwater and marine. Size: 0.35-21 mm. No growth lines on valves (cf. Conchostraca). Over 1700 species known, about 1/3 freshwater. "Microscopic clams with legs".

a Widely distributed, clean to polluted water. Generally free living except for a few rare commensals.

b Pollution significance is not known.

5 Subclass Copepoda - copepods. Five - 6 pairs of thoracic appendages, the 1st 4 biramous. Body cylindrical, divided into two sections (Cephalothorax or metasome, and abdomen or urosome). Some parasitic forms are greatly modified. Locomotion by means of 2nd antenna, which is unbranched (cf: Cladocera). Many virtually transparent. Up to 3 mm.

a Distribution world wide, freshwater and marine. One of most abundant of animal plankton.

b Development includes a complex series of growth stages. Eggs carried over from year to year in mud. Resist drying and freezing.

6 Subclass Branchiura - fish lice. With suction cups on head appendages, body strongly depressed, ectoparasitic on fish. Sometimes considered to be an order of the copepoda. Of primary importance as fish parasites.

7 Subclass Malacostraca - (no collective common name). Body usually consisting of 20 segments (approximately 5 in head, 8 in thorax, 7 in abdomen) and 19 pairs of appendages exclusive of eyes. Approximately 30,000 species known nearly 800 in N. America. Of the 12 orders recognized, only 4 have freshwater representatives.

a Order Mysidacea - oppossum shrimps. Essentially a marine group, but three species inhabit our fresh waters. Superficially resemble marine shrimps of commerce. Carapace thin and does not completely cover thorax. Stalked compound eyes extremely large. Nektonic in nature, with thoracic appendages adapted for swimming.

1) Mysis relicta inhabits deep cold oligotropic lakes in northern states east of Great Plains. Up to 30 mm. Circumboreal.

2) Acanthomysis awatchensis occurs in lakes, rivers, and brackish estuaries of Pacific N.W.

3) Taphromysis louisianae Gulf coast region, also brackish water. Up to 8 mm.

b Order Isopoda - aquatic sow bugs or pill bugs. Some fifty freshwater species represent approximately 5% of all known species, many of which are terrestrial as well as marine. Size: 5 - 20 mm.

1) Ovoid, flattened dorsoventrally. Most of the thoracic and abdominal segments are unfused, giving the animals a many-jointed appearance. Lateral extensions of each segment and the absence of any large protruding structures combine to give an overall impression of an army tank in life.

2) Generally inhabit springs, brooks and subterranean waters. In the north central states they are often abundant in small polluted streams that go dry in summer, of which they are frequently almost the only inhabitants.

c Order Amphipoda - scuds or sideswimmers. Chiefly a marine group with about 50 American freshwater species. Size: 5-20 mm.

1) Body is laterally compressed, few fused segments as in isopods. Eyes generally well developed except in subterranean species.

2) Occur in a wide variety of relatively unpolluted waters where ample oxygen is present. Generally nocturnal. Soft waters generally favored, but Gammarus limnaeus is common in hard waters and Hyalella azteca is sometimes found in alkaline and brackish waters.

3) Subterranean species are common in cavernous areas, and hence frequently appear in well waters.

4) Scuds serve as intermediate hosts for a variety of parasites of waterfowl, amphibians, and fishes, but not so far as known for man.

d Order Decapoda - freshwater shrimps, crayfish; also marine lobsters, and crabs.

Only about 160 species of this huge, essentially marine group, are found in the fresh waters of N. America, of which about 130 are crayfishes. True freshwater crabs occur in Mexico and in the West Indies and one species has been reported in Florida. Other marine crabs occasionally invade fresh waters for extended periods and some have become essentially terrestrial. Decapods are in general from the Rocky Mountain region.

1) Decapod shrimps (prawns) can be distinguished by the laterally compressed rostrum. Commercial freshwater prawn culture techniques have been developed. Size 3-23 cm.

2) The crayfishes (crawdads, crabs) are the predominant group of freshwater decapods. Their shell is heavier and the pincers usually strongly developed. There are many burrowing forms and many species have rather specialized habitat preferences. Unfortunately, however, their pollution significance has not been worked out. In general it can be said that they can tolerate a considerable amount of pollution. Size, (exclusive of antennae): 15-130 mm.

C Class Arachnida - spiders, scorpions, ticks, and mites. The water mites (Parasitegona) have become extensively adapted to fresh waters, and these are almost exclusively restricted to freshwater, there being very few marine and no terrestrial forms. They are readily recognized by their bright colors, globular to ovoid shape, and clambering and swimming habits. Other types of Acari or mites found in marine and freshwater are in the Halacaridae and Oribatei. These crawling types are sometimes found in large numbers in activated sludge. Size 0.4 - 3.0 mm.

1 Superficially resemble minute spiders, but have no division into cephalothorax and abdomen. All evident segmentation has been lost. Four pairs of legs are present in the adult stage.

2 Mites are carnivorous or parasitic, feeding on aquatic invertebrates. Some are commensal on mussels, and host specific.

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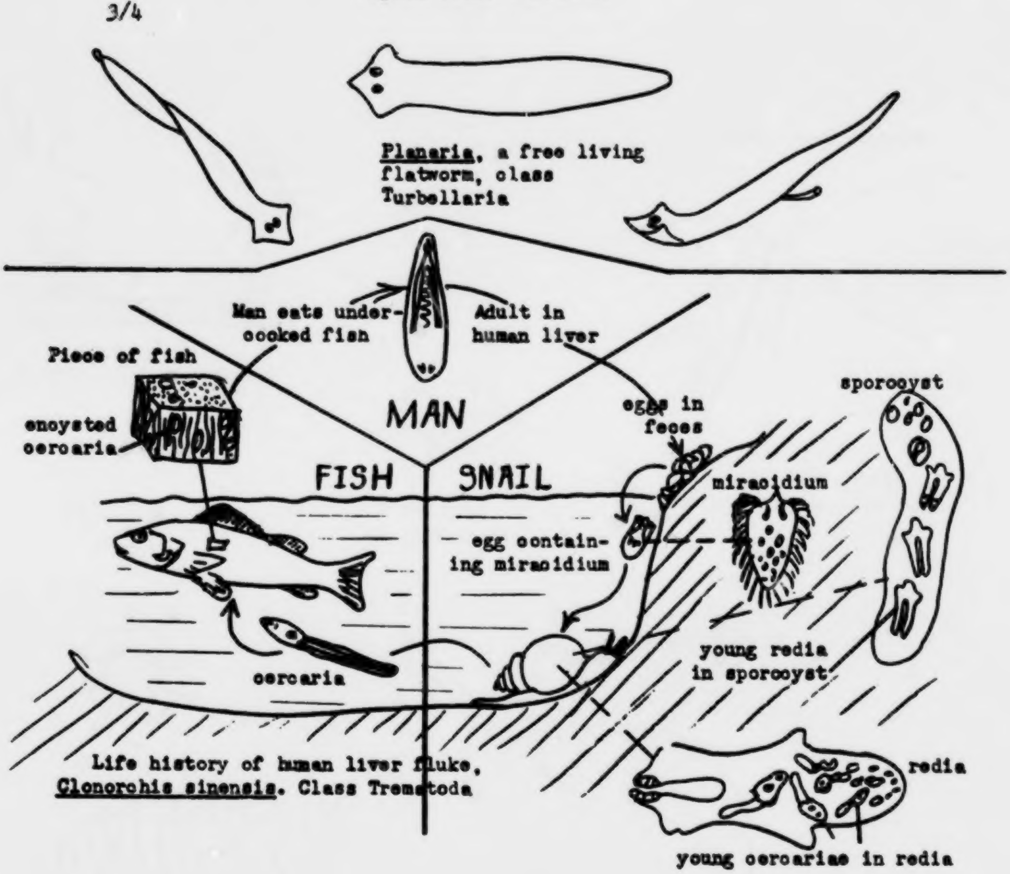
This outline was prepared by H.W. Jackson, Chief Biologist, National Training Center, WPO, EPA, Cincinnati, OH 45268 and revised by R.M. Sinclair, Aquatic Biologist, National Training Center.

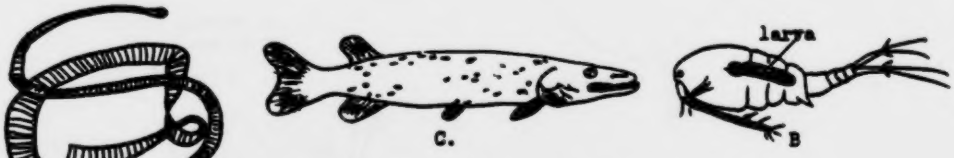
Flatworms

Phylum PLATYHELMINTHES


3/4
Man eats under-cooked fish
Adult in human liver
Piece of fish
encysted cercaria
MAN
FISH
SNAIL
eggs in feces
sporocyst
miracidium
egg containing miracidium
cercaria
young redia in sporocyst
redia
young cercariae in redia

Planaria, a free living flatworm, class Turbellaria

Life history of human liver fluke, Clonorchis sinensis. Class Trematoda



Aspects in the life cycle of the human tapeworm Diphyllobothrium latum, class Cestoda. A, adult as in human intestine; B, procercoid larva in copepod; C, plerocercoid larva in flesh of pickerel(X-ray view).

H.W.Jackson

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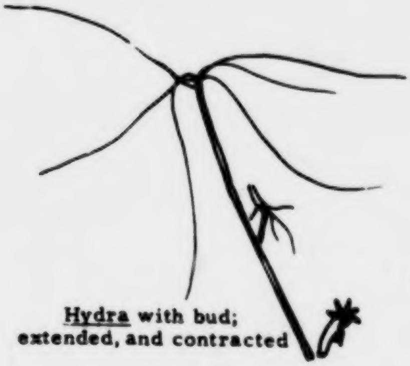
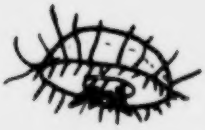
MINOR PHYLA

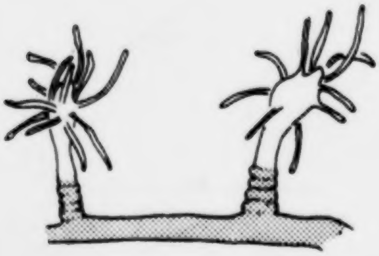
Phylum Coelenterata



Hydra with bud; extended, and contracted

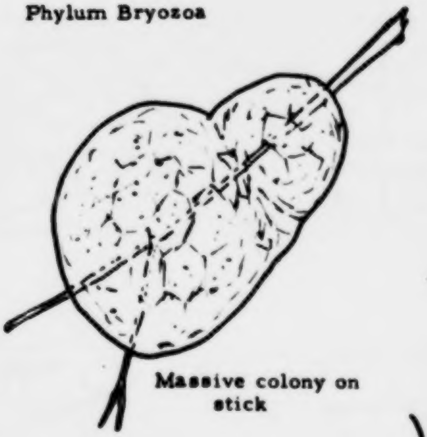


Medusa of *Craspedacusta*

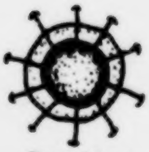


Cordylophora caspia colony

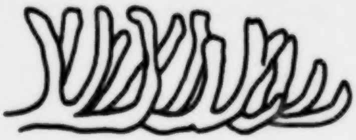
Phylum Bryozoa



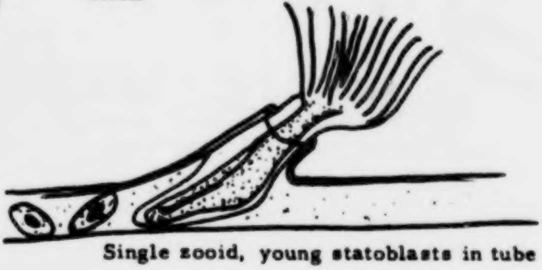
Massive colony on stick



Statoblast



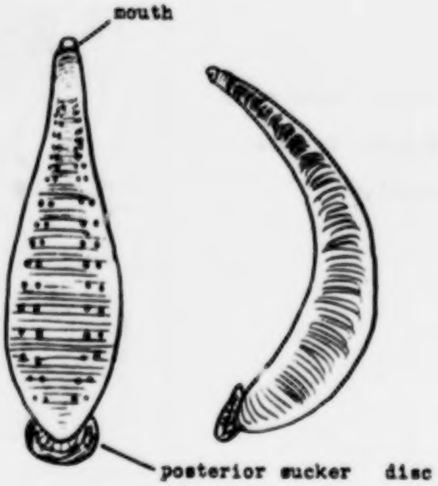
Creeping colony on rock



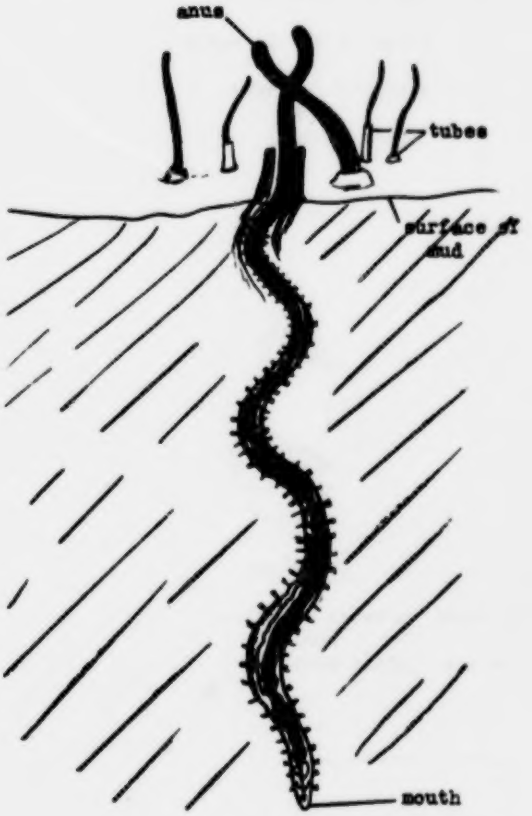
Single zooid, young statoblasts in tube

FRESH WATER ANNELID WORMS

Phylum Annelida


mouth
posterior sucker disc

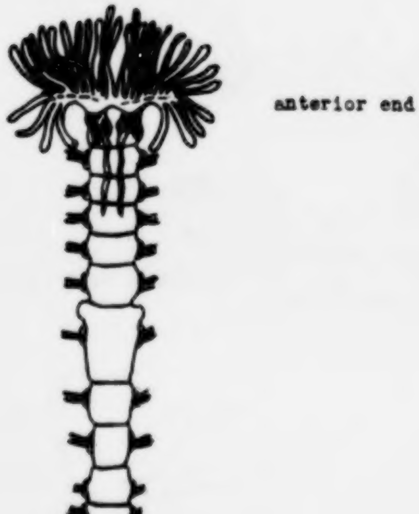
Class Hirudinea, leeches
(After Hegner)


anus
tubes
surface of mud
mouth

Class Oligochaeta, earthworms

Ex: Tubifex , the sludgeworm

(After Liebman)


anterior end

Class Polychaeta , polychaet worms

Ex: Manayunkia, a minute, rare, tube building worm.
(After Leidy)

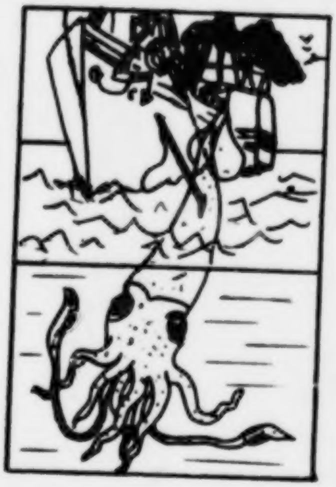
H.W.Jackson PLATE XII c

SOME MOLLUSCAN TYPES

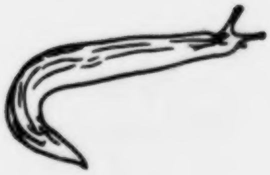
Class: Cephalopoda:

Squids, octopus,

cuttlefish.

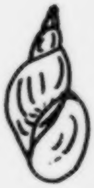


Exclusively marine. The giant squid shown was captured in the Atlantic in the early ninteenth century. (After Hegner)



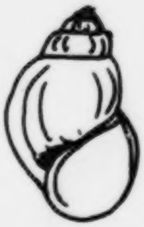
Limax,

a slug



Lymnaea

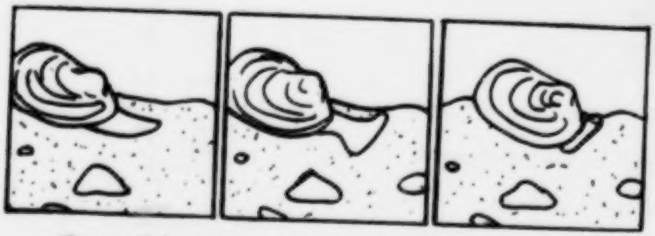
an air breathing snail



Campeloma

a water breathing snail

Class: Gastropoda; snails and slugs. (After Buchsbaum)



Class: Pelecypoda; clams, mussels, oysters.

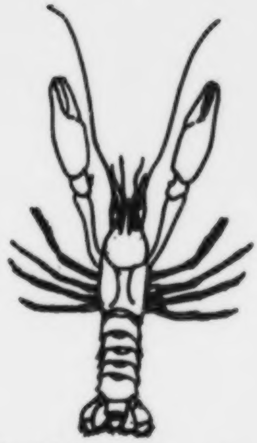
Locomotion of a freshwater clam, showing how foot is extended, the tip expanded, and the animal pulled along to its own anchor. (After Buchsbaum)

PLATE XII d

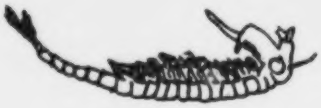
H.W.Jackson

3/4

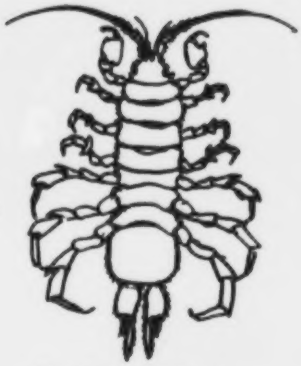
Class CRUSTACEA



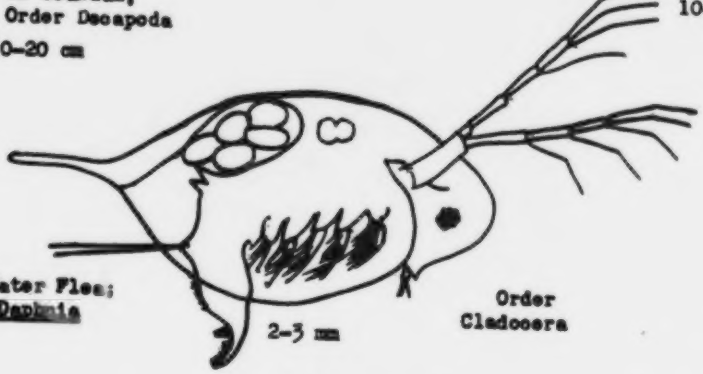
Crayfish, or crawdad; *Cambarus*, Order Decapoda
10-20 cm



Fairy Shrimp; *Eubranchipus*, Order Phyllopoda
20-25 mm



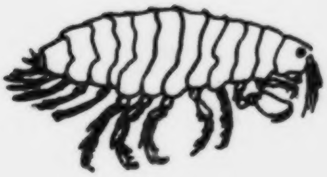
Sow Bug; *Asellus*, Order Isopoda
10-20 mm



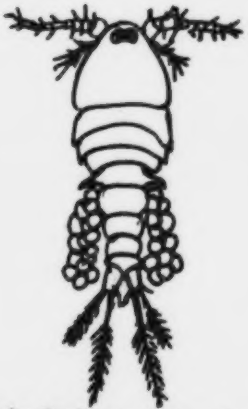
Water Flea; *Daphnia*

2-3 mm

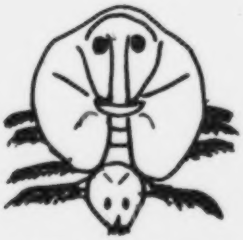
Order Cladocera



Scud; *Hyalella*
Order Amphipoda
10-15 mm



Copepod; *Cyclops*, Order Copepoda
2-3 mm



Fish Louse, *Argulus*; a parasitic Copepod
5-6 mm

H.W.Jackson

PLATE X

FISHES

I INTRODUCTION: What is a fish?

A A fish is a gill-breathing aquatic vertebrate with fins (exceptions noted).

B Other Aquatic Vertebrates

1 Amphibia - frogs, toads, salamanders

a Modern amphibia do not have scales.

b Tadpole stages easily recognized.

c Pollutional significance not studied to date. Frogs often observed in polluted waters but not aquatic salamanders.

2 Reptilia - snakes and turtles

a Relatively independent of water quality as long as it is not irritating.

b Carnivorous types would be starved out of polluted areas for lack of food.

3 Mammalia - muskrats, beavers

a Generally inhabit wilderness areas where heavy pollution is not a problem.

II STRUCTURE AND PHYSIOLOGY

A Fins

1 A typical fish has two sets of paired fins, the pectoral and pelvic, comparable (homologous) to our arms and legs respectively. Certain ancient fish could walk on their lobe-like fins, and some specialized modern forms likewise.

2 Unpaired dorsal, anal, and caudal or tail fins, complete the fin structures.

3 Any or all of these may be missing, and fleshy extra fins such as the "adipose" fins of trout and salmon, catfishes, etc., may appear. Extra paired fins too are known. The dorsal fin is often divided into two or more sections known as 1st, 2nd, 3rd, etc., dorsal fins.

4 Fins may be supported by soft rays or stiff spines or both.

B The body of a typical fish is covered with scales.

1 Four types of scales are recognized.

a The most primitive are bony plates bearing tooth-like projections as found in sharks and rays.

b Smooth bony plates such as those of the gar and dogfish are somewhat higher in specialization.

c Thin smooth roundish "cycloid" scales are characteristic of the more primitive of the modern "bony" fishes like herring or trout.

d Roundish scales with tiny spines or cteni are characteristic of the highest fishes like the black basses. These are called ctenoid scales.

2 Cycloid and ctenoid scales are nonliving material like hair or fingernails, covered with a thin layer of living tissue cells. This tissue is easily injured as by handling a fish with dry hands.

C Respiration of a typical fish is by means of blood gills (Cf: tracheal gills of insects).

1 Gills, like lungs, are a device for bringing the blood into close proximity to the environment.

2 Certain ancient fishes and their modern descendents, the lungfishes, breathed air. Some of the modern bonyfishes like certain catfishes also have a limited air breathing capacity.

D The maintenance of a constant internal osmotic pressure of their body fluids in competition with their environment is a problem which fishes have that terrestrial animals with their waterproof skins do not have.

1 The slime covering body and gills is an important part of the regulatory mechanism.

2 Marine fishes live in an environment that tends to dehydrate the body. Consequently water appears to be swallowed from time to time in order to replace that lost through the gills and general body surface. This may make marine fishes more susceptible to some toxic substances which would then be taken internally instead of simply contacting the skin externally.

3 Freshwater fishes live in an environment with an osmotic pressure far lower than that of body fluids. Toxic substances would then be less likely to be taken internally except with food.

III REPRODUCTION AND DEVELOPMENT

A Although almost infinite variety exists, most fishes lay their eggs externally in the water, at which time the male showers them with milt. Such species are said to be oviparous. In some species such as the familiar guppy however, fertilization is internal and the eggs develop and hatch in the mother's body. No nourishment is known to be transmitted from mother to developing young. Such species are said to be ovoviviparious. The young are thus "born alive."

1 Most fish eggs hatch before all the food material stored in the egg as yolk is used up. Embryonic development is still going on and they are truly in a larval or pre-adult condition. During their first hours or days of free life, they are thus still independent of their environment for food. This early stage is known as yolk sac fry or simply sac fry.

2 The young continue to be called fry, or advanced fry until they approach an inch in length, when they are referred to as fingerlings.

3 Fry which differ greatly from the form of the adult may be referred to as larvae.

B Some fish lay their eggs in the same general location in which they live as adults. Others travel to some distant place, such as from lakes or rivers up into small streams, from deep water to shoal, from the ocean to fresh water, from fresh water to the ocean, etc. These are called breeding migrations.

1 Fish that normally live in freshwater and travel to the ocean to reproduce are called catadromous. The freshwater eel is the best known example.

2 Those that live in the sea and lay their eggs in freshwater are called anadromous. Striped bass, shad and certain other herrings, and the salmons are well known examples. Occasionally, a group of anadromous fish will get lost in the inland waters and not be able to find its way back to the sea. These are called landlocked varieties and are usually somewhat smaller than their non-lan-locked relatives.

3 Pollution or other factors which either block a breeding migration or destroy a spawning bed may completely destroy

a species, even though the adults in their natural habitat are untouched.

IV CLASSIFICATION OF FISHES

Fishes may be classified or grouped in many different ways.

A Food, Feeding Habits and Ecological Interrelationships

Fish, like many other animal groups, include carnivores, herbivores, and detritus feeders or scavengers.

1 Scavengers may specialize on bottom feeding like certain suckers, carps, and catfishes. Others may take any organic matter they can find, whereever they can find it. Scavengers are often provided with barbels or feeders which help in locating food, especially in turbid water.

2 Herbivores may feed on the larger, vascular plants as some carps or they may specialize on the microscopic phytoplankton, in which case they are called plankton feeders. Plankton feeders usually have weak mouths and fine gill rakers for straining the plankton out of the water.

3 The carnivorous or predatory species feed essentially on living animals. They may specialize on invertebrates or other fish, in which case they may be called piscivorous.

- a Piscivorous fish usually depend essentially on eyesight for locating their food, and hence turbid water is a handicap.
- b The carnivorous fish in general include most of the game fish.
- c Small species of fish which are not used directly by man but are used extensively as food by piscivorous species are often referred to as forage fish.

B Classification with reference to their desirability or to mode of use by man has been widely used. An example of such a system is as follows:

1 Commercial - those that occur in sufficient quantities to support a fishery.

- a Food fishes: white-fish, salmon, cod
- b Product fishes: sharks, blue back herrings

2 Game or sport - those captured essentially for sport. Many species fall into both this and the commercial categories such as the trouts, blackbasses, striped bass, etc.

- a Gamefish are sometimes considered to be those which are of interest to man only for the catching, as the tarpon.
- b Fish which are taken, even though in sport, but which are also eaten are then called panfish. Sometimes panfish refers only to the smaller of the edible gamefish.

3 Rough fishes are those such as the gars, and the bowfins, which are of little or no use to man. Some, such as the carp, are classed in different groups in different regions according to local custom.

C A classification developed with reference to standard methods of reporting fish population data for reservoirs is as follows: (Surber '59):

Group 1. Predatory Game Fish - bass, crappies, trout, etc.

Group 2. Non-predatory Game Fish - sunfish, rock bass, perch, etc.

Group 3. Non-predatory Food Fish - carp, drum, buffalo, suckers, bullheads, etc.

Group 4. Predatory Food Fish - catfish, gar, bowfin, etc.

Group 5. Forage Fish (Non-predatory) - gizzard shad, threadfin shad, Gambusia, minnows, etc.

D The scientific classification system for fishes lists many thousands of species. Three great groups of living fishes occur in this country: the Agnatha or jawless fishes, the Chondrichthyes or cartilaginous fishes and the Osteichthyes or (modern) boney fishes. Some additional groups occur in other parts of the world.

1 The jawless fishes are represented in fresh water by the lampreys, which have in recent years invaded the Great Lakes from the sea and wrecked havoc on the native species.

2 The cartilaginous fishes are the sharks, skates, and rays, primarily a marine group.

3 The vast majority of fishes with which most of us are familiar belong to the Osteichthyes or bony fishes, a few typical families are listed below:

a The family Acipenseridae or sturgeons are a primitive group, famed for their roe which is sold as caviar. More or less covered with large, bony plates. Formerly extremely abundant and large in size.

b Family Lepisosteidae - the gars. These Voracious fish are covered with hard, enamel-like, rhomboid scales. Some species may grow to great size. Widely regarded as "trash" fish.

c The family Salmonidae includes the trouts, salmons, whitings, and graylings. Scales are cycloid and always small, an extra or adipose fin on the back, eggs are very large, favored by cold water. In the Pacific Salmon, but one set of reproductive cells is formed in the life of the individual, which therefore dies after spawning once.

d The family Catostomidae is the suckers. The head is naked of scales, jaws toothless, mouth usually protractile, lips generally thick and fleshy. Feed on plants and small animals.

e The family Cyprinidae is the carp-dace-minnow group. Here too the head is naked, and the body usually scaled. Ventral fins usually well back. Teeth are lacking in the jaws. Certain bones in the back of the throat known as the pharyngeals are strongly developed however, and bear from 1 to 3 series of teeth which are often of importance in identification. Upwards of 1800 species, abundant where present at all, both in numbers and variety. Generally small in size although Leucosomus corporalis the chub, roach, or fallfish may reach a length of 18 inches in the east, and related species 5 to 6 feet on the west coast. Because of the many similar species, this is one of the most difficult groups in zoology to identify to species.

Two genera, Cyprinus which includes the common carp, and Carassius including the goldfish have been introduced and become widely established. Both are native to China. Other introduced Cyprinids have so far not become widely established.

f Family Ictaluridae, the freshwater catfishes. Body more or less elongate, naked. Eight barbels or feelers in head region. Dorsal fin short, an adipose fin behind. First ray of dorsal and pectorals developed as stout spines. Many excellent food fish. Very tenacious of life.

g Family Centrarchidae - sunfishes and freshwater basses. Scales ctenoid. Dorsal fin continuous but may be in two sections, the anterior spined, the posterior rayed. Generally carnivorous. Typical of eastern North America but have been widely introduced in other areas. Nest builders.

4 Additional well known families of bony fishes are listed below:

Polyodontidae	-	paddlefishes
Amiidae	-	bowfins
Gasterosteidae	-	stickelbacks
Cyprinodontidae	-	killifishes
Serranidae	-	sea basses
Ictaluridae	-	freshwater catfishes
Percidae	-	perches and darters
Cottidae	-	sculpins
Atherinidae	-	silversides
Clupeidae	-	herrings
Osmeridae	-	smelts
Salmonidae	-	whitefishes, trouts, etc.
Anguiledae	-	eel
Poeciliidae	-	guppies, mosquitofishes
Gadidae	-	cods, hakes, burbots
Esocidae	-	pikes and pickerels
Sciaenidae	-	drums

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1 American Fisheries Society. A List of Common and Scientific Names of Fishes From the United States and Canada. Special Publication No. 2. Am. Fish Soc. Dr. E.A. Seaman, Sec.-Treas. Box 483, McLean, Va. (Price $1.00 paper, $2.00 cloth.) 1960.

2 Bailey, Reeve M. A Revised List of the Fishes of Iowa with Keys for Identification. IN: Iowa Fish and Fishing. State of Iowa. Super. of Printing. (Excellent color pictures.) 1956.

3 Eddy, Samuel. How to Know the Freshwater Fishes. Wm. C. Brown Co. Dubuque, Iowa. 1957.

4 Hubbs, C.L., and Lagler, K.F. Fishes of the Great Lakes Region, Bull. Cranbrook Inst. Sci. Bloomfield Hills, Michigan. 1949.

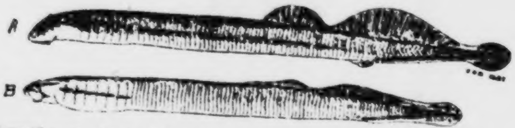
5 Lagler, K.F. Freshwater Fishery Biology. Wm. C. Brown Co. Dubuque, Iowa. 1952.

6 Surber, E.S. Suggested Standard Methods of Reporting Fish Population Data for Reservoirs. Proc. 13th Ann. Conf. S.E. Assoc. Game & Fish Comm. pp. 313-325. Baltimore, Md. October 25-27, 1959.

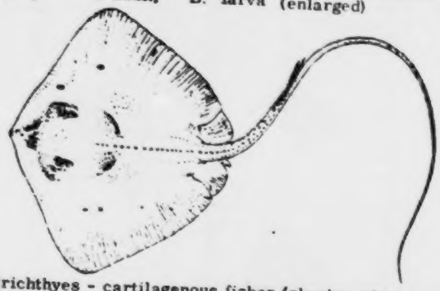
7 Trautman, M.B. The Fishes of Ohio. Ohio State Univ. Press. (An outstanding example of a state study.) Columbus, Ohio. 1957.

This outline was prepared by H.W. Jackson, Chief Biologist, National Training Center, Water Programs Operations, EPA, Cincinnati, OH 45268.

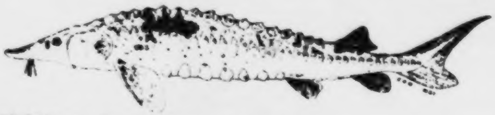
SOME PRIMITIVE FISHES



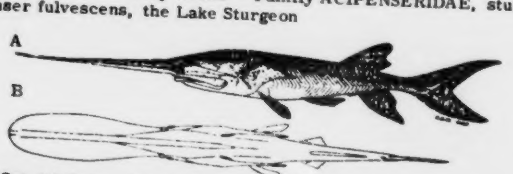
Class Agnatha, jawless fishes (lampreys and hagfishes) - Family PETROMYZONTIDAE, the lampreys. Lampetra aepyptera, the Brook Lamprey A: adult, B: larva (enlarged)



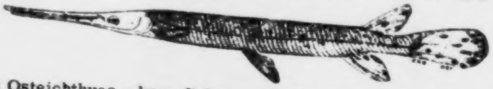
Class Chondrichthyes - cartilagenous fishes (sharks, skates, rays) Family DASYATIDAE - stingrays. Dasyatis centroura, the Roughtail Stingray



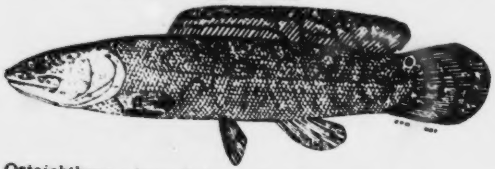
Class Osteichthyes - bony fishes - Family ACIPENSERIDAE, sturgeon. Acipenser fulvescens, the Lake Sturgeon



Class Osteichthyes - bony fishes - Family POLYODONTIDAE, the paddlefishes. Polyodon spathula, the Paddlefish. A:side view B:top view



Class Osteichthyes - bony fishes - Family LEPISOSTEIDAE - gars Lepisosteus osseus, the Longnose Gar



Class Osteichthyes - bony fishes - Family AMIIDAE, bowfins Amia calva, the Bowfin

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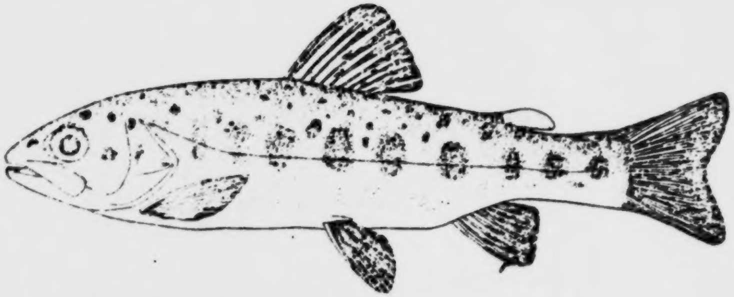
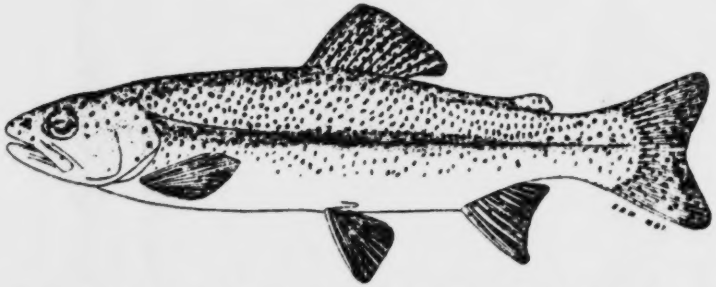
Bl. AQ. pl. 91. 6. 60

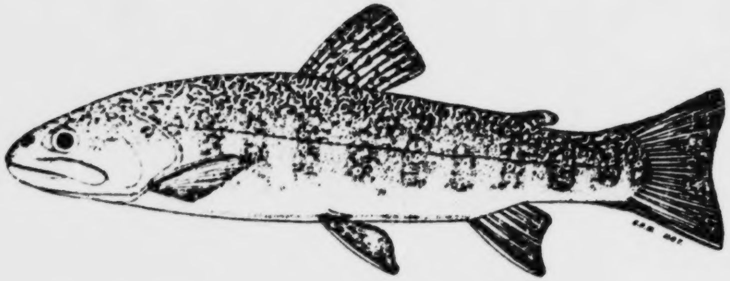
Family SALMONIDAE



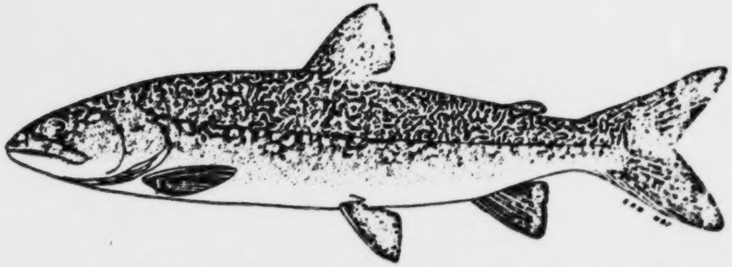
Salmo trutta - brown trout



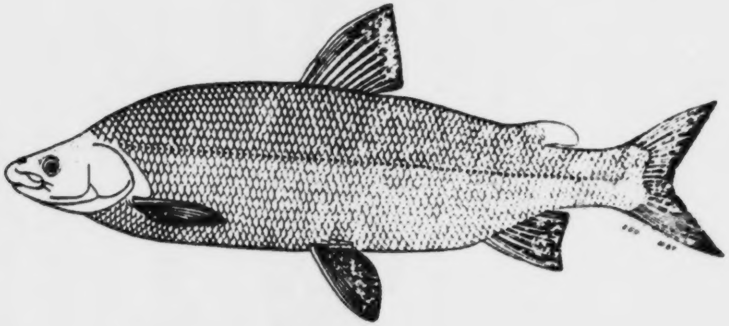
Salmo gairdneri - rainbow (or steelhead) trout



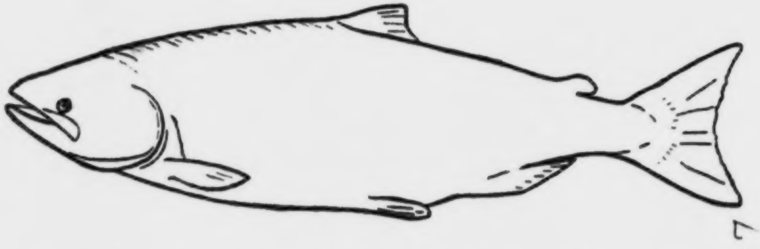
Salvelinus fontinalis - brook trout



Salvelinus namaychush - the lake trout



Coregonus clupeaformis - lake whitefish



Oncorhynchus tshawytscha - the chinook salmon

10-7

Reproduced with permission; Trautman, 1947 (except Chinook salmon after Jordan '05).

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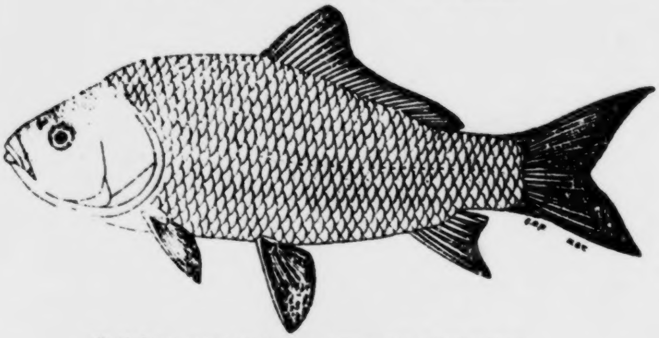
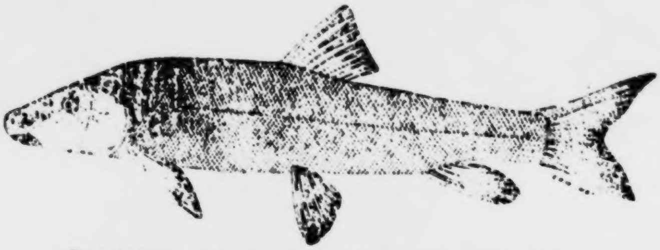
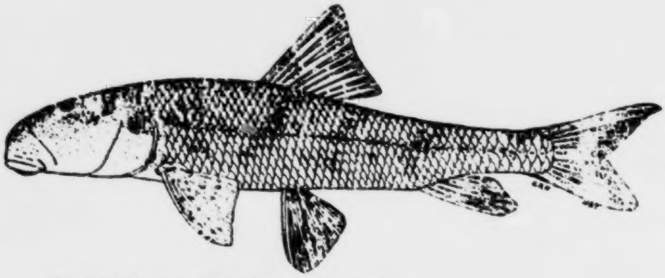
Family CATOSTOMIDAE - the suckers



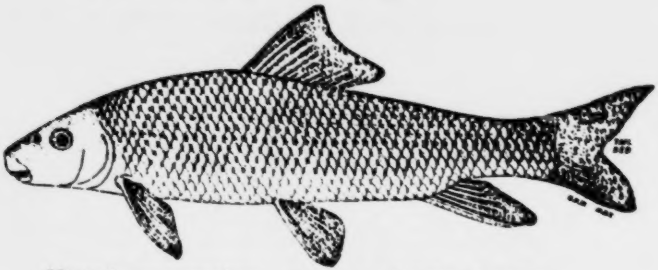
Ictiobus cyprinellus - bigmouth buffalofish



Catostomus catostomus - eastern longnose sucker



Hypentelium nigricans - hog sucker



Moxostoma aureolum - northern shorthead redhorse

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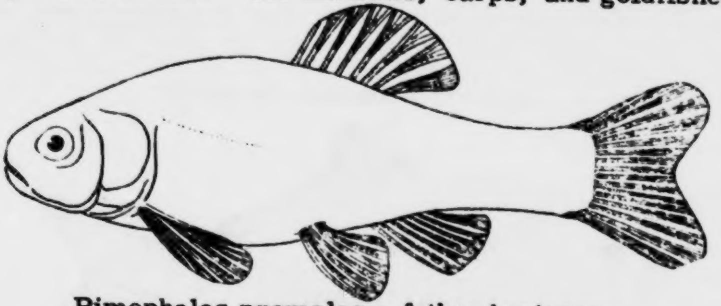
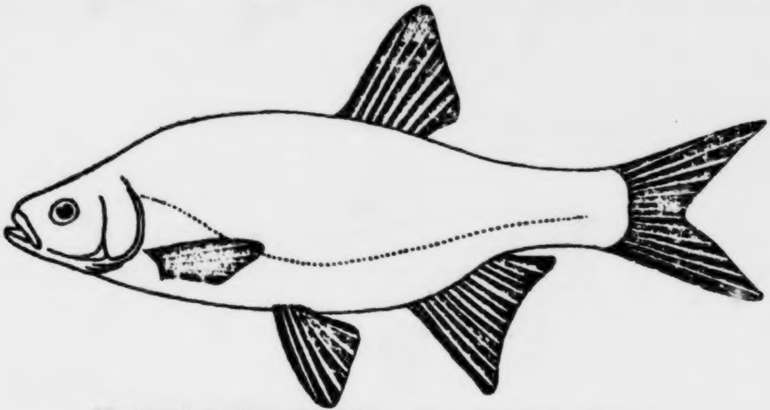
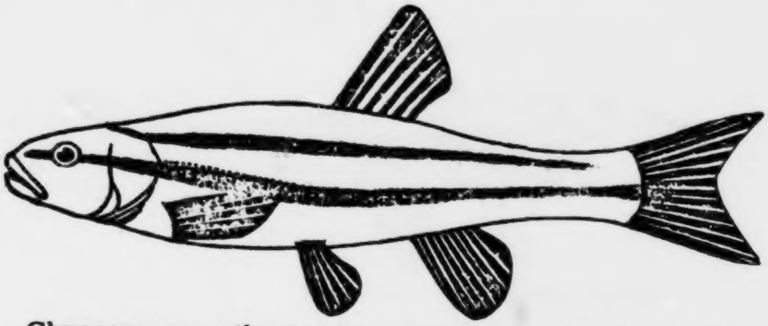
Family CYPRINIDAE - the minnows, carps, and goldfishes



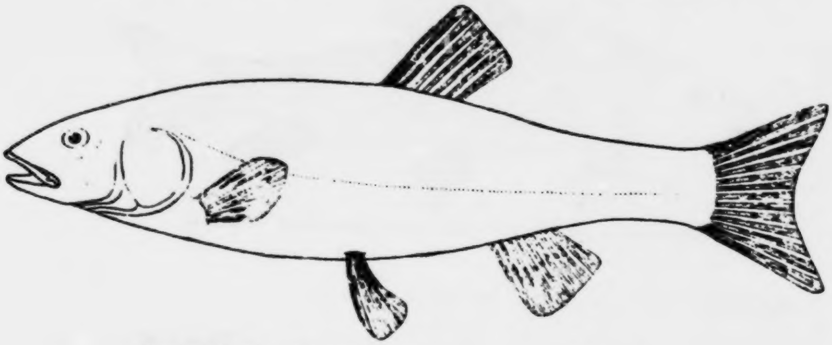
Pimephales promelas - fathead minnow



Notemigonus crysoleucas - golden shiner



Chrosomus erythrogaster - southern redbelly dace

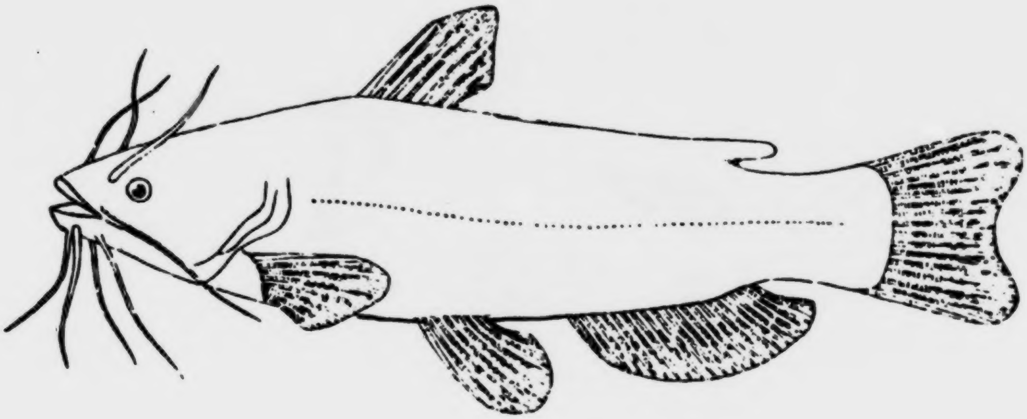


Semotilus atromaculatus - creek chub

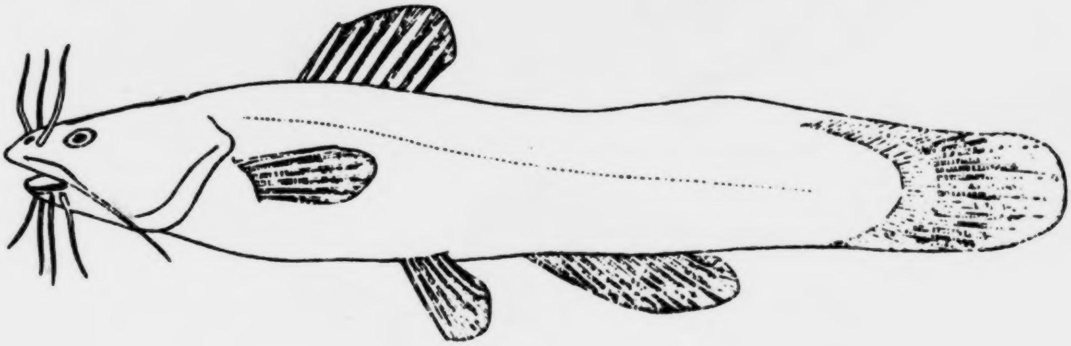
Reproduced with permission; Hart, Doudoroff, and Greenbank, 1945.

10-9

Family ICTALURIDAE - the freshwater catfishes



Ictalurus nebulosus - brown bullhead

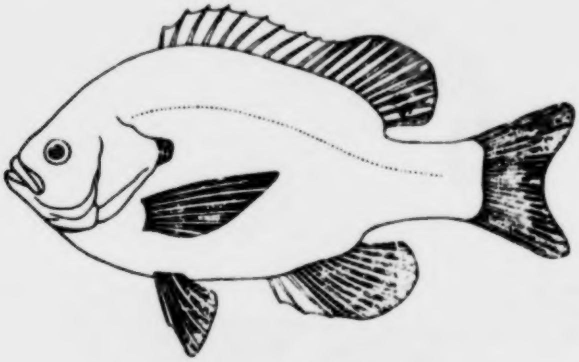


Noturus insignis - margined madtom

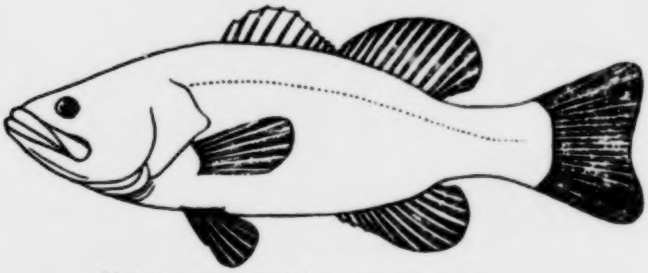
Reproduced with permission; Hart, Doudoroff, and Greenbank, 1945.

BI. AQ. pl. 9i. 6. 60

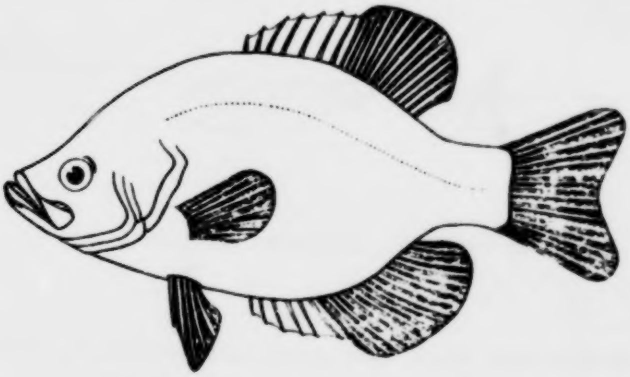
Family CENTRARCHIDAE - the sunfishes



Lepomis macrochirus - bluegill



Micropterus salmoides - largemouth bass



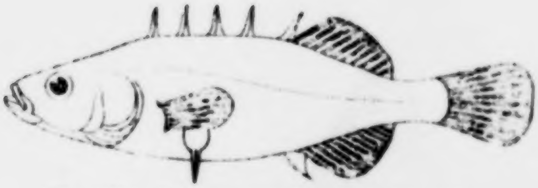
Pomoxis nigromaculatus - black crappie

Reproduced with permission; Hart, Doudoroff, and Greenbank, 1945.

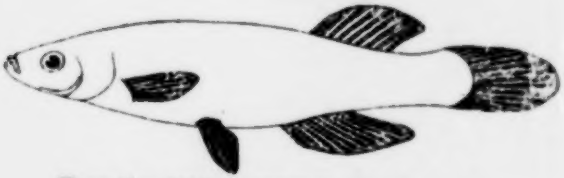
BI. AQ. pl. 9k. 6. 60

10-11

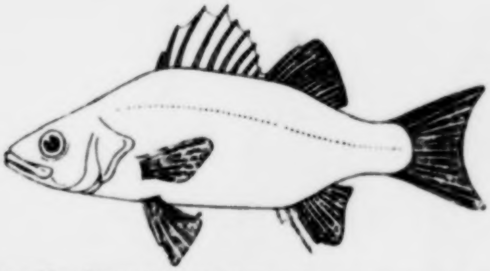
TYPES OF BONY FISHES I



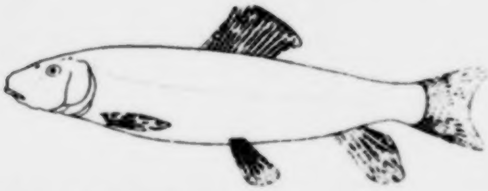
Family GASTEROSTEIDAE, the Sticklebacks. *Eucalia inconstans*, the brook stickleback



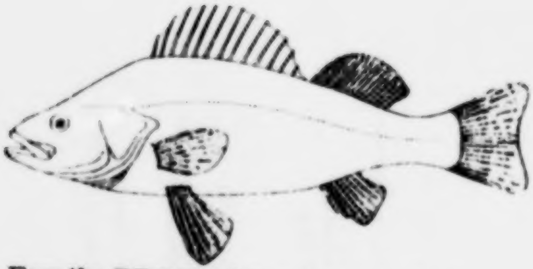
Family CYPRINODONTIDAE, the Killifishes. *Fundulus notatus*, the blackstripe topminnow



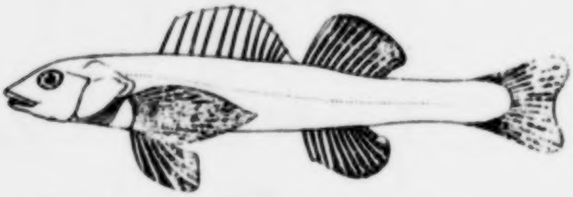
Family SERRANIDAE, the sea basses. *Roccus americanus*, the white perch



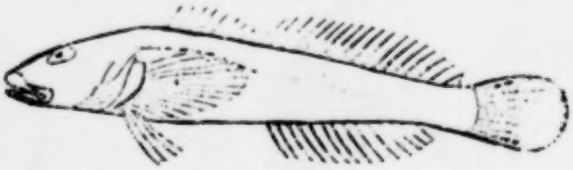
Family CATOSTOMIDAE, the suckers. *Catostomus commersonii*, the white sucker



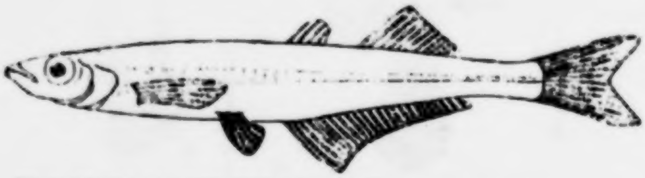
Family PERCIDAE - the perches. *Perca flavescens*, the yellow perch



Family PERCIDAE, the perches. *Etheostoma nigrum*, the johnny darter



Family COTTIDAE, the sculpins. *Cottus bairdii*, the mottled sculpin

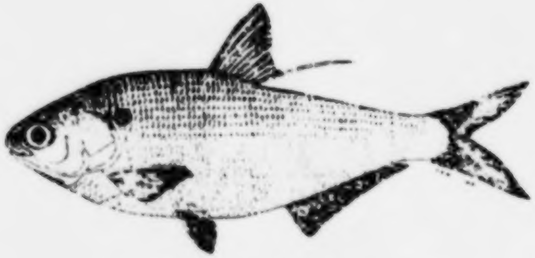


Family ATHERINIDAE, the silversides. *Labidesthes sicculus*, the brook silverside.

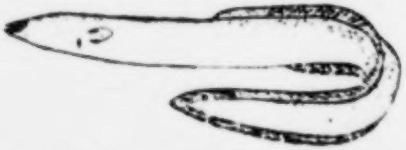
Reproduced with permission; Hart, Doudoroff and Greenbank, 1945.

10-12

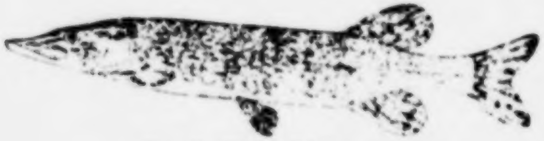
TYPES OF BONY FISHES



Family CLUPEIDAE - herrings
Dorosoma cepedianum - the eastern gizzard shad



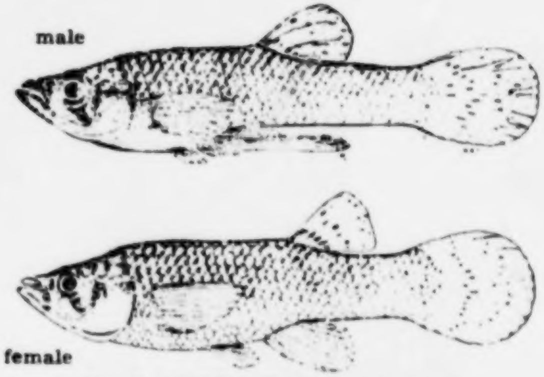
Family ANGUILLEDAE - freshwater eels
Anguilla rostrata - the American eel



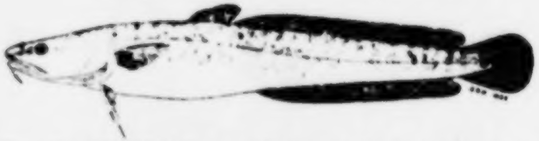
Family ESOCIDAE - pikes
Esox lucius - the northern pike

Reproduced with permission; Trautman, 1957.

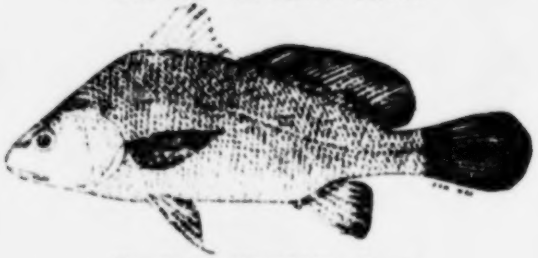
Bl. AQ. pl. 9m. 6.60



Family POECILIIDAE - livebearers
Gambusia affinis - the mosquitofish

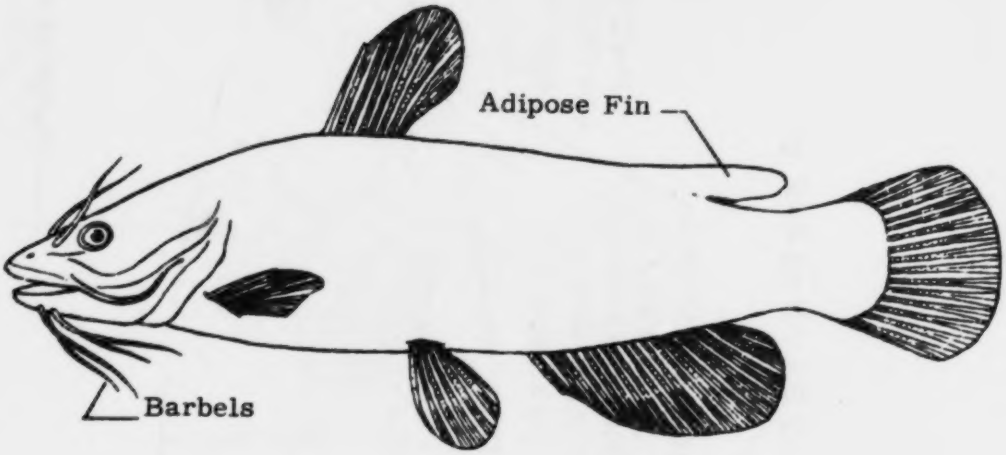


Family GADDIDAE - codfishes, hakes, haddock; burbot
Lota lota - the eastern burbot

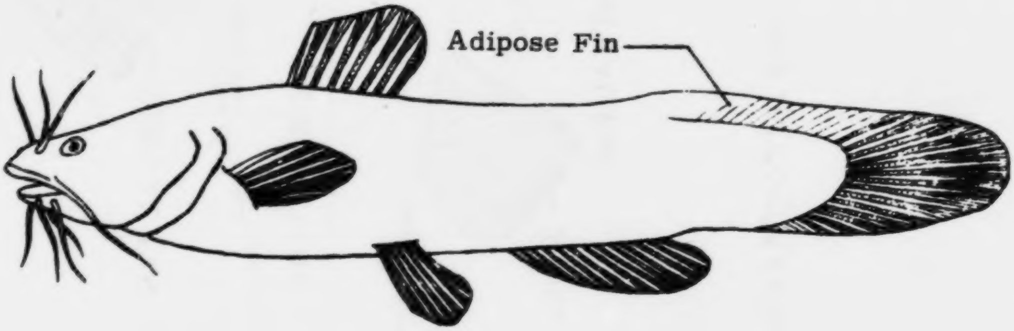


Family SCIAENIDAE - drums
Aplodinotus grunniens - the freshwater drum

ADIPOSE FINS - in catfishes


Adipose Fin
Barbels

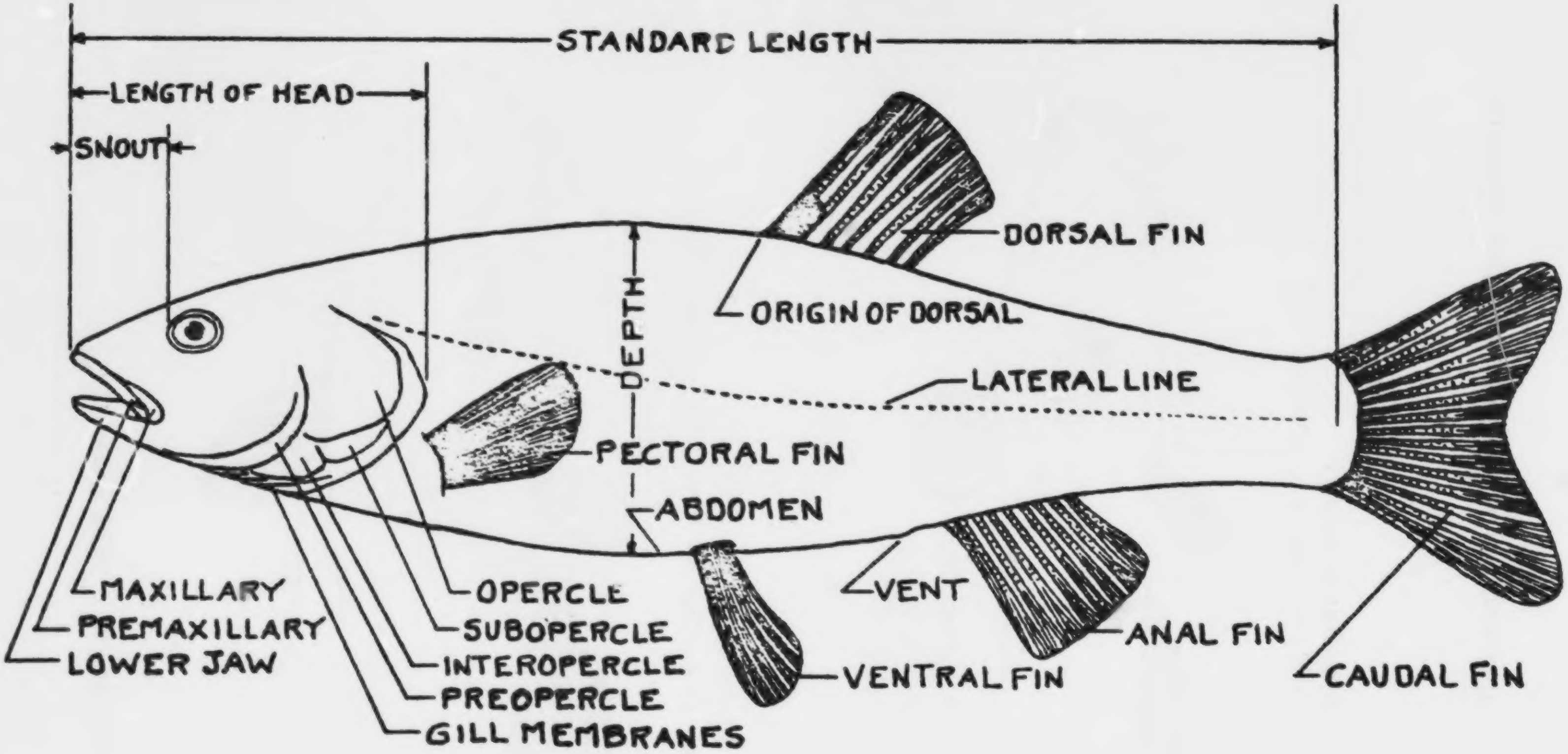
The Adipose Fin does not extend to the Caudal Fin
(Ictalurus nebulosus)


Adipose Fin

The Adipose Fin extends to the Caudal Fin
(Noturus insignis)

Reproduced with permission; Hart, Doudoroff and Greenbank, 1945.

10-14

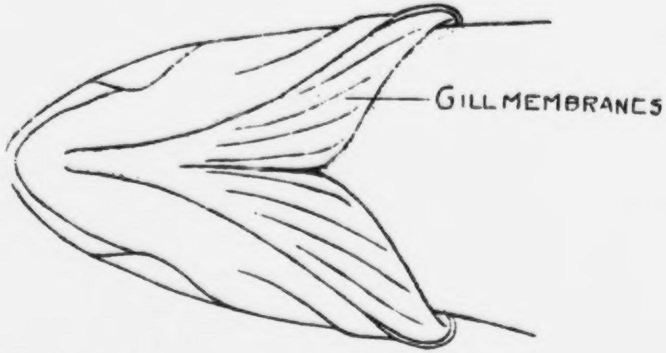

STANDARD LENGTH
LENGTH OF HEAD
SNOUT
DEPTH
DORSAL FIN
ORIGIN OF DORSAL
LATERAL LINE
PECTORAL FIN
ABDOMEN
MAXILLARY
PREMAXILLARY
LOWER JAW
OPERCLE
SUBOPERCLE
INTEROPERCLE
PREOPERCLE
GILL MEMBRANES
VENT
ANAL FIN
VENTRAL FIN
CAUDAL FIN

A SOFT-RAYED FISH, SEMOTILUS ATROMACULATUS

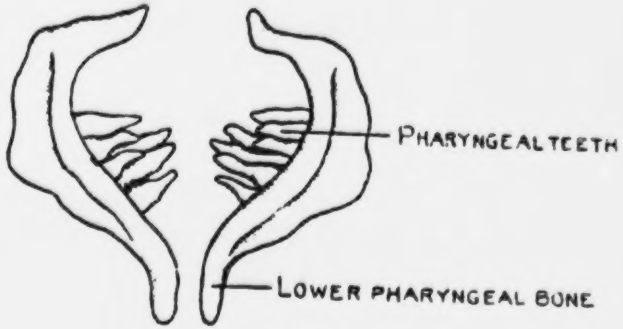
Hart, Doudoroff, and
Greenbank, 1945

BI. AQ. pl. 9a. 6. 60

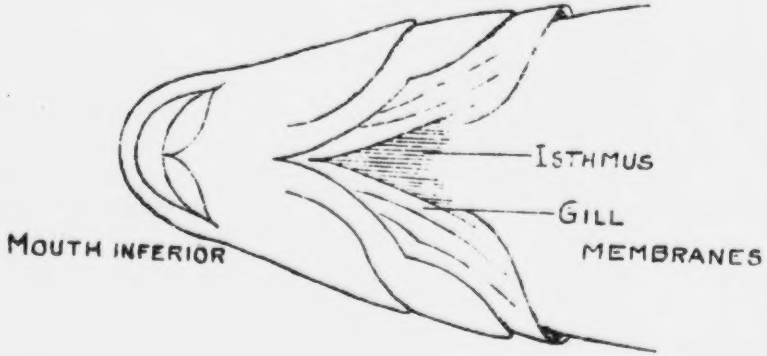
10-15


GILL MEMBRANES

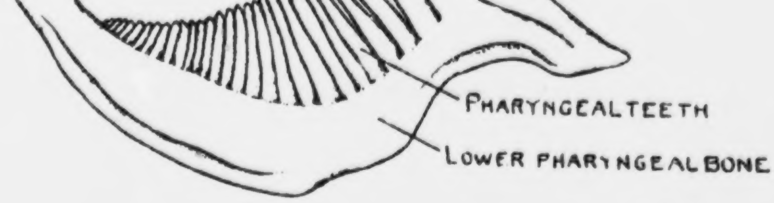
GILL MEMBRANES FREE OF THE ISTHMUS.
AND SEPARATE


PHARYNGEAL TEETH
LOWER PHARYNGEAL BONE

FORM OF PHARYNGEAL TEETH IN THE
CYPRINIDAE.


ISTHMUS
GILL
MEMBRANES
MOUTH INFERIOR

GILL MEMBRANES SEPARATE AND CONNECTED TO
THE ISTHMUS.


PHARYNGEAL TEETH
LOWER PHARYNGEAL BONE

COMB-LIKE TEETH IN THE
CATOSTOMIDAE.

10-16

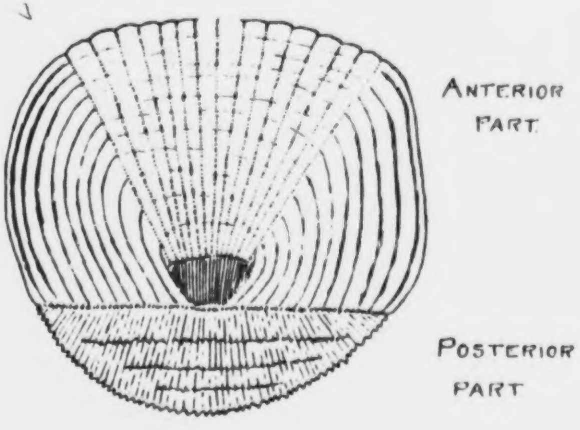
Hart, Doudoroff, and
Greenbank, 1945

This outline was prepared by H. W. Jackson

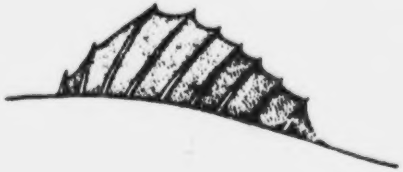
BI. AQ. pl. 9c. 6. 60

FIN AND SCALE STRUCTURES

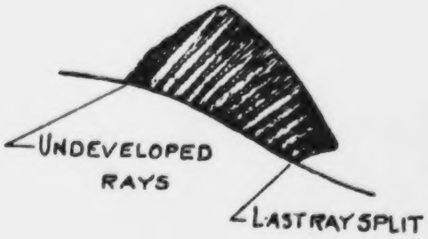
10-17


Anterior
Part
Posterior
Part

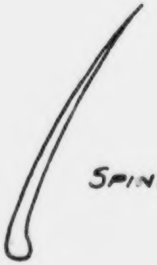
Ctenoid Scale



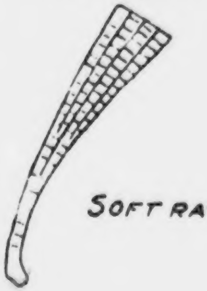
A spinous dorsal fin.


Undeveloped
Rays
Last ray split

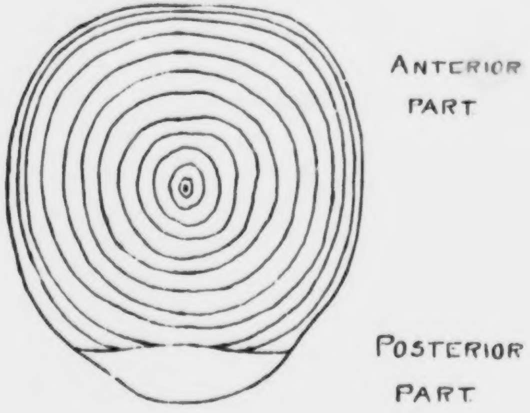
A soft rayed dorsal fin.



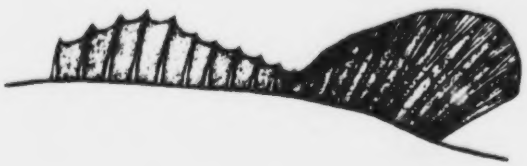
Spine



Soft ray


Anterior
Part
Posterior
Part

Cycloid scale



A dorsal fin composed of spinous and soft rays.

produced with permission; Hart, Doudoroff, and Greenbank, 1945.

FUNGI AND THE "SEWAGE FUNGUS" COMMUNITY

I INTRODUCTION

A Description

Fungi are heterotrophic achylorophyllous plant-like organisms which possess true nuclei with nuclear membranes and nucleoli. Dependent upon the species and in some instances the environmental conditions, the body of the fungus, the thallus, varies from a microscopic single cell to an extensive plasmodium or mycelium. Numerous forms produce macroscopic fruiting bodies.

B Life Cycle

The life cycles of fungi vary from simple to complex and may include sexual and asexual stages with varying spore types as the reproductive units.

C Classification

Traditionally, true fungi are classified within the Division Eumycotina of the Phylum Mycota of the plant kingdom. Some authorities consider the fungi an essentially monophyletic group distinct from the classical plant and animal kingdoms.

II ACTIVITY

In general, fungi possess broad enzymatic capacities. Various species are able to actively degrade such compounds as complex polysaccharides (e.g., cellulose, chitin, and glycogen), proteins (casein, albumin, keratin), hydrocarbons (kerosene) and pesticides. Most species possess an oxidative or microaerophilic metabolism, but anaerobic catabolism is not uncommon. A few species show anaerobic metabolism and growth.

III ECOLOGY

A Distribution

Fungi are ubiquitous in nature and members of all classes may occur in large numbers in aquatic habitats. Sparrow (1968) has briefly reviewed the ecology of fungi in freshwaters with particular emphasis on the zoosporic phycomycetes. The occurrence and ecology of fungi in marine and estuarine waters has been examined recently by a number of investigators (Johnson and Sparrow, 1961; Johnson, 1968; Myers, 1968; van Uden and Fell, 1968).

B Relation to Pollution

Wm. Bridge Cooke, in a series of investigations (Cooke, 1965), has established that fungi other than phycomycetes occur in high numbers in sewage and polluted waters. His reports on organic pollution of streams (Cooke, 1961; 1967) show that the variety of the Deuteromycete flora is decreased at the immediate sites of pollution, but dramatically increased downstream from these regions.

Yeasts, in particular, have been found in large numbers in organically enriched waters (Cooke, et al., 1960; Cooke and Matsuura, 1963; Cooke, 1965b; Ahearn, et al., 1968). Certain yeasts are of special interest due to their potential use as "indicator" organisms and their ability to degrade or utilize proteins, various hydrocarbons, straight and branch chained alkyl-benzene sulfonates, fats, metaphosphates, and wood sugars.

C "Sewage Fungus" Community (Plate I)

A few microorganisms have long been termed "sewage fungi." The most common microorganisms included in this group are the iron bacterium Sphaerotilus natans and the phycomycete Leptomitus lacteus.

1 Sphaerotilus natans is not a fungus; rather it is a sheath bacterium of the order chlamydobacteriales. This polymorphic bacterium occurs commonly in organically enriched streams where it may produce extensive slimes.

a Morphology

Characteristically, S. natans forms chains of rod shaped cells (1.1 - 2.0μ x 2.5 - 17μ) within a clear sheath or trichome composed of a protein-polysaccharidae-lipid complex. The rod cells are frequently motile upon release from the sheath; the flagella are lophotrichous. Occasionally two rows of cells may be present in a single sheath. Single trichomes may be several mm in length and bent at various angles. Empty sheaths, appearing like thin cellophane straws, may be present.

b Attached growths

The trichomes are cemented at one end to solid substrata such as stone or metal, and their cross attachment and bending gives a superficial similarity to true fungal hyphae. The ability to attach firmly to solid substrates gives S. natans a selective advantage in the population of flowing streams. For more thorough reviews of S. natans see Prigsheim (1949) and Stokes (1954).

2 Leptomitus lacteus also produces extensive slimes and fouling flocs in fresh waters. This species forms thalli typified by regular constrictions.

a Morphology

Cellulin plugs may be present near the constrictions and there may be numerous granules in the cytoplasm. The basal cell of the thallus may possess rhizoids.

b Reproduction

The segments delimited by the partial constrictions are converted basipetally to sporangia. The zoospores are diplanetic (i.e., dimorphic) and each possesses one whiplash and one tinsel flagellum. No sexual stage has been demonstrated for this species.

c Distribution

For further information on the distribution and systematics of L. lacteus see Sparrow (1960), Yerkes (1966) and Emerson and Weston (1967). Both S. natans and L. lacteus appear to thrive in organically enriched cold waters (5°-22°C) and both seem incapable of extensive growth at temperatures of about 30°C.

d Gross morphology

Their metabolism is oxidative and growth of both species may appear as reddish brown flocs or stringy slimes of 30 cm or more in length.

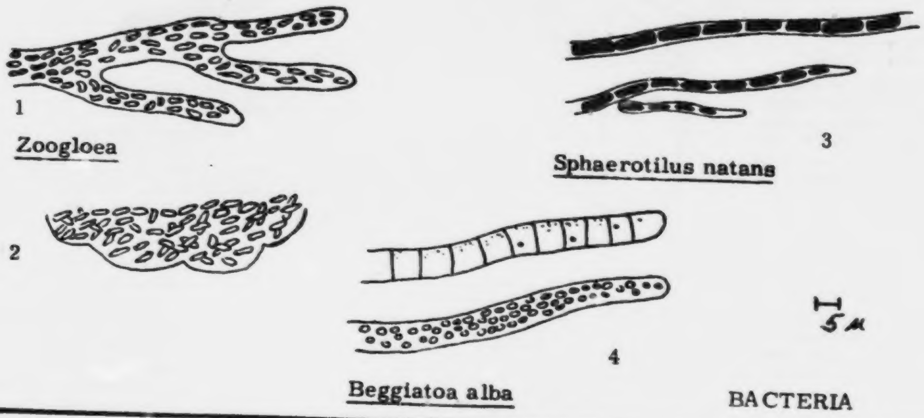
e Nutritive requirements

Sphaerotilus natans is able to utilize a wide variety of organic compounds, whereas L. lacteus does not assimilate simple

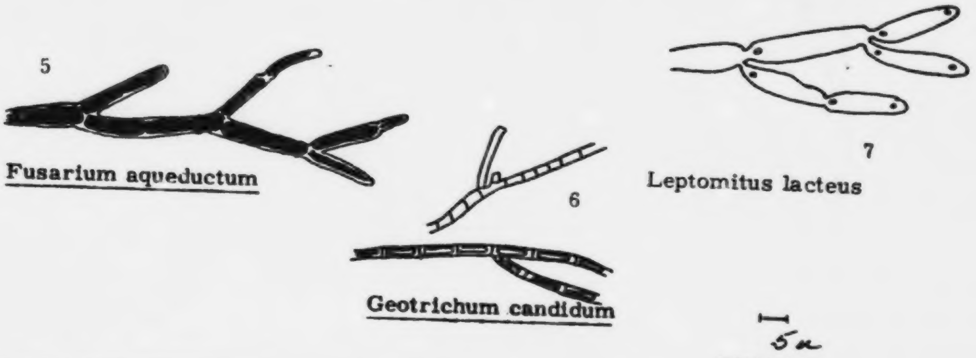
PLATE I

"SEWAGE FUNGUS" COMMUNITY OR "SLIME GROWTHS"

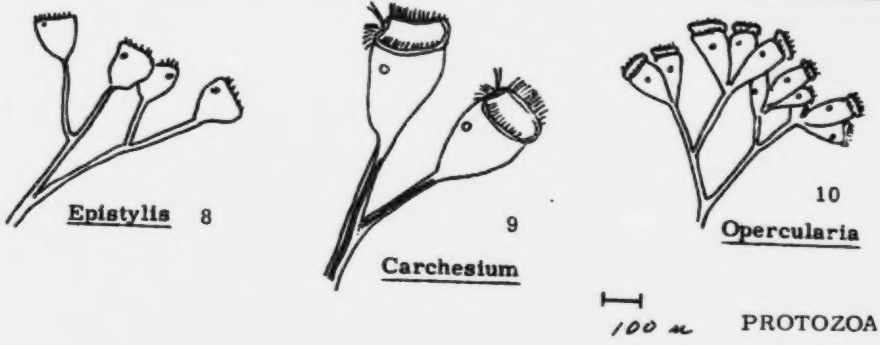
(Attached "filamentous" and slime growths)


1
Zoogloea
2
3
Sphaerotilus natans
4
Beggiatoa alba
5 μ

BACTERIA


5
Fusarium aqueductum
6
Geotrichum candidum
7
Leptomitus lacteus
5 μ

FUNGI


Epistylis 8
9
Carchesium
10
Opercularia
100 μ

PROTOZOA

PLATE II

REPRESENTATIVE FUNGI

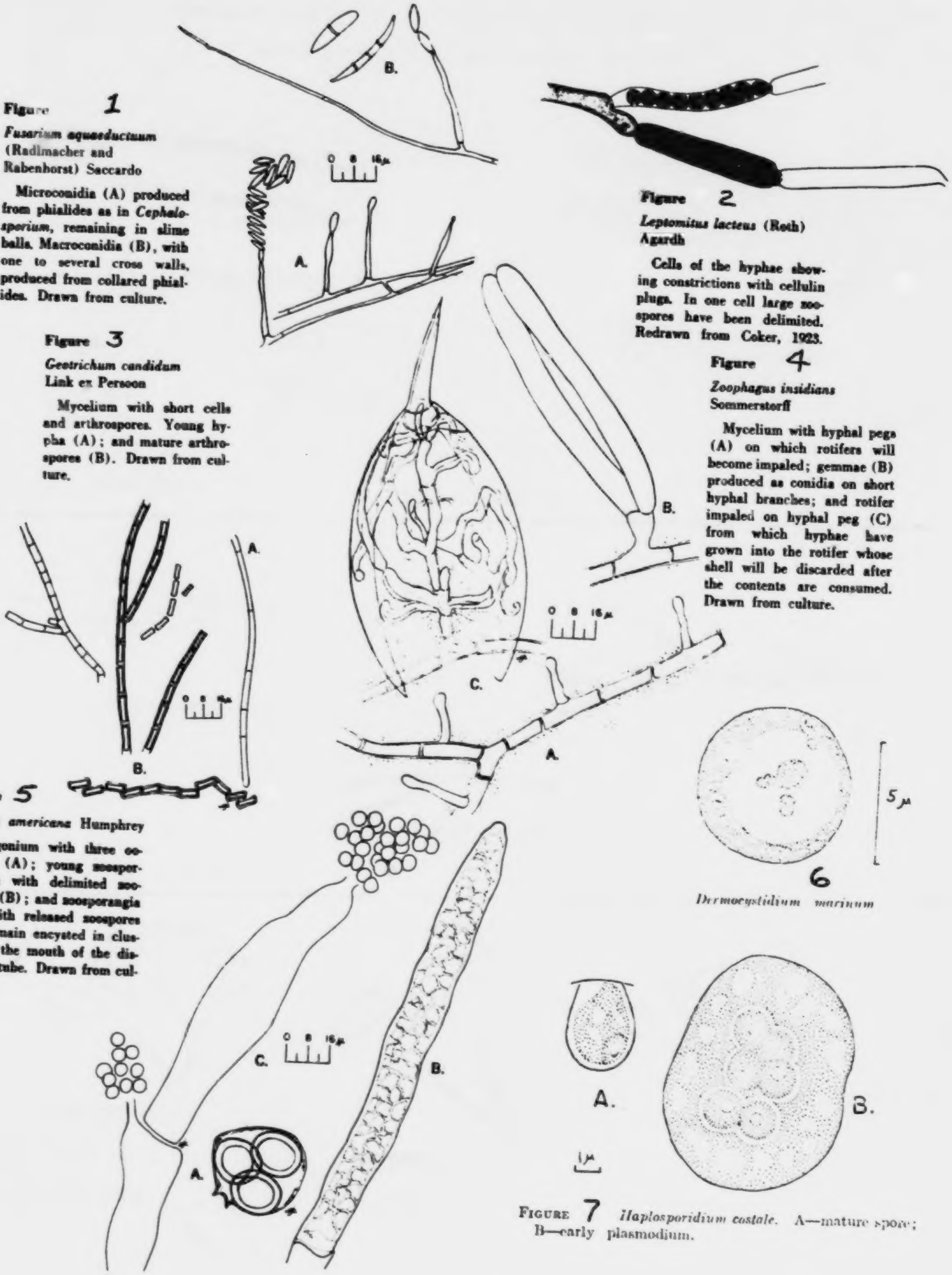


Figure 1

Fusarium aquaeductuum (Radlmacher and Rabenhorst) Saccardo

Microconidia (A) produced from phialides as in *Cephalosporium*, remaining in slime balls. Macroconidia (B), with one to several cross walls, produced from collared phialides. Drawn from culture.

Figure 2

Leptomitus lacteus (Roth) Agardh

Cells of the hyphae showing constrictions with cellulin plugs. In one cell large zoospores have been delimited. Redrawn from Coker, 1923.

Figure 3

Geotrichum candidum Link ex Persoon

Mycelium with short cells and arthrospores. Young hypha (A); and mature arthrospores (B). Drawn from culture.

Figure 4

Zoophagus insidians Sommerstorff

Mycelium with hyphal pegs (A) on which rotifers will become impaled; gemmae (B) produced as conidia on short hyphal branches; and rotifer impaled on hyphal peg (C) from which hyphae have grown into the rotifer whose shell will be discarded after the contents are consumed. Drawn from culture.

Figure 5

Achlya americana Humphrey

Oogonium with three oospores (A); young zoosporangium with delimited zoospores (B); and zoosporangia (C) with released zoospores that remain encysted in clusters at the mouth of the discharge tube. Drawn from culture.

6 *Dermocystidium marinum*

FIGURE 7 *Haplosporidium costale.* A—mature spore; B—early plasmodium.

Figures 1 through 5 from Cooke; Figures 6 and 7 from Galtsoff.

sugars and grows most luxuriantly in the presence of organic nitrogenous wastes.

3 Ecological roles

Although the "sewage fungi" on occasion attain visually noticeable concentrations, the less obvious populations of deuteromycetes may be more important in the ecology of the aquatic habitat. Investigations of the past decade indicate that numerous fungi are of primary importance in the mineralization of organic wastes; the overall significance and exact roles of fungi in this process are yet to be established.

D Predacious Fungi

1 Zoophagus insidians

(Plate II, Figure 4) has been observed to impair functioning of laboratory activated sludge units (see Cooke and Ludzack).

2 Arthrobotrys is usually found along with Zoophagus in laboratory activated sludge units. This fungus is predacious upon nematodes. Loops rather than "pegs" are used in snaring nematodes.

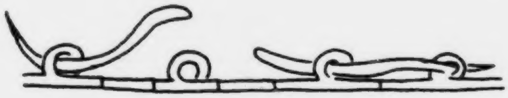


PLATE II (Figure 4)

IV CLASSIFICATION

In recent classification schemes, classes of fungi are distinguished primarily on the basis of the morphology of the sexual and zoosporic stages. In practical schematics, however, numerous fungi do not demonstrate these stages. Classification must therefore be based on the sum total of the morphological and/or physiological characteristics. The extensive review by Cooke (1963) on methods of isolation and classification of fungi from sewage and polluted waters precludes the need herein of extensive keys and species illustrations. A brief synopsis key of the fungi adapted in part from Alexopholous (1962) is presented on the following pages.

This outline was prepared by Dr. Donald G. Ahearn, Professor of Biology, Georgia State College, Atlanta, Georgia 30303.

KEY TO THE MAJOR TAXA OF FUNGI

1 Definite cell walls lacking, somatic phase a free living Plasmodium....................................... Sub-phylum Myxomycotina ..(true slime molds)..Class Myxomycetes

1' Cell walls usually well defined, somatic phase not a free-living Plasmodium.......................................(true fungi)...............Sub-phylum Eumycotina 2

2 Hyphal filaments usually coenoctytic, rarely septate, sex cells when present forming oospores or zygospores, aquatic species propagating asexually by zoospores, terrestrial species by zoospores, sporangiospores conidia or conidia-like sporangia ."Phycomycetes"... 3

The phycomycetes are generally considered to include the most primitive of the true fungi. As a whole, they encompass a wide diversity of forms with some showing relationships to the flagellates, while others closely resemble colorless algae, and still others are true molds. The vegetative body (thallus) may be non-specialized and entirely converted into a reproductive organ (holocarpic), or it may bear tapering rhizoids, or be mycelial and very extensive. The outstanding characteristics of the thallus is a tendency to be nonseptate and, in most groups, multinucliate; cross walls are laid down in vigorously growing material only to delimit the reporductive organs. The spore unit of nonsexual reproduction is borne in a sporangium, and, in aquatic and semiaquatic orders, is provided with a single posterior or anterior flagellum or two laterally attached ones. Sexual activity in the phycomycetes characteristically results in the formation of resting spores.

2' (1') Hyphal filaments when present septate, without zoospores, with or without sporangia, usually with conida; sexual reproduction absent or culminating in the formation of asci or basidia 8

3 (2) Flagellated cells characteristically produced 4

3' Flagellated cells lacking or rarely produced 7

4 (3) Motile cells uniflagellate 5

4' Motile cells biflagellate..6

5 (4) Zoospores posteriorly uniflagellate, formed inside the sporangium...class..Chytridiomycetes

The Chytridiomycetes produce asexual zoospores with a single posterior whiplash flagellum. The thallus is highly variable; the most primitive forms are unicellular and holocarpic and in their early stages of development are plasmodial (lack cell walls), more advanced forms develop rhizoids and with further evolutionary progress develop mycelium. The principle chemical component of the cell wall is chitin, but cellulose is also present. Chytrids are typically aquatic organisms but may be found in other habitats. Some species are chitinolytic and/or keratinolytic. Chytrids may be isolated from nature by baiting (e.g. hemp seeds or pine pollen) Chytrids occur both in marine and fresh water habitats and are of some economic importance due to their parasitism of algae and animals. The genus Dermocystidium may be provisionally grouped with the chytrids. Species of this genus cause serious epidemics of oysters and marine and fresh water fish.

5' Zoospores anteriorly uniflagellate, formed inside or outside the sporangium............class ....Hyphochytridiomycetes

These fungi are aquatic (fresh water or marine) chytrid-like fungi whose motile cells possess a single anterior flagellum of the tinsel type (feather-like). They are parasitic on algae and fungi or may be saprobic. Cell walls contain chitin with some species also demonstrating cellulose content. Little information is available on the biology of this class and at present it is limited to less than 20 species.

6 (4') Flagella nearly equal, one whiplash the other tinsel.................class.......Oomycetes

A number of representatives of the Oomycetes have been shown to have cellulosic cell walls. The mycelium is coenocytic, branched and well developed in most cases. The sexual process results in the formation of a resting spore of the oogamous type, i.e., a type of fertilization in which two heterogametangia come in contact and fuse their contents through a pore or tube. The thalli in this class range from unicellular to profusely branched filamentous types. Most forms are eucarpic; zoospores are produced throughout the class except in the more highly advanced species. Certain species are of economic importance due to their destruction of food crops (potatoes and grapes) while others cause serious diseases of fish (e.g. Saprolegina parasitica). Members of the family Saprolegniaceae are the common "water molds" and are among the most ubiquitous fungi in nature. The order Lagenidiales includes only a few species which are parasitic on algae, small animals, and other aquatic life. The somatic structures of this taxon are holocarpic and endobiotic. The sewage fungi are classified in the order Leptomitales. Fungi of this order are characterized by the formation of refractile constrictions; "cellulin plugs" occur throughout the thalli or, at least, at the bases of hyphae or to cut off reproductive structures. Leptomitus lacteus may produce rather extensive fouling flocs or slimes in organically enriched waters.

6' Flagella of unequal size, both whiplash .... class... Plasmodiophoromycetes

Members of this class are obligate endoparasites of vascular plants, algae, and fungi. The thallus consists of a plasmodium which develops within the host cells. Nuclear division at some stages of the life cycle is of a type found in no other fungi but known to occur in protozoa. Zoosporangia which arise directly from the plasmodium bear zoospores with two unequal anterior falgella. The cell walls of these fungi apparently lack cellulose.

7 (3') Mainly saprobic, sex cell when present a zygospore.................. class ... Zygomycetes

This class has well developed mycelium with septa developed in portions of the older hyphae; actively growing hyphae are normally non-septate. The asexual spores are non-motile sporangiospores (aplanospores). Such spores lack flagella and are usually aerialy disseminated. Sexual reproduction is initiated by the fusion of two gametangia with resultant formation of a thick-walled, resting spore, the zygospore. In the more advanced species, the sporangia or the sporangiospores are conidia-like. Many of the Zygomycetes are of economic importance due to their ability to synthesize commercially valuable organic acids and alcohols, to transform steroids such as cortisone, and to parasitize and destroy food crops. A few species are capable of causing disease in man and animals (zygomycosis).

7' Obligate commensals of arthropods, zygospores usually lacking ...... class.... Trichomycetes

The Trichomycetes are an ill-studied group of fungi which appear to be obligate commensals of arthropods. The trichomycetes are associated with a wide variety of insecta, diplopods, and crustacea of terrestrial and aquatic (fresh and marine) habitats. None of the members of this class have been cultured in vitro for continued periods of times with any success. Asexual reproduction is by means of sporangiospores. Zygospores have been observed in species of several orders.

8 (2') Sexual spores borne in asci.................................... class....... Ascomycetes

In the Ascomycetes the products of meiosis, the ascospores, are borne in sac like structures termed asci. The ascus usually contains eight ascospores, but the number produced may vary with the species or strain. Most species produce extensive septate mycelium. This large class is divided into two subclasses on the presence or absence of an ascocarp. The Hemiascomycetidae lack an ascocarp and do not produce ascogenous hyphae; this subclass includes the true yeasts. The Euascomycetidae usually are divided into three series (Plectomycetes, Pyrenomycetes, and Discomycetes) on the basis of ascocarp structure.

8' Sexual spores borne on basidia................................. class..... Basidiomycetes

The Basidiomycetes generally are considered the most highly evolved of the fungi. Karyogamy and meiosis occur in the basidium which bears sexual exogenous spores, basidiospores. The mushrooms, toadstools, rusts, and smuts are included in this class.

8'' Sexual stage lacking....................... Form class.(Fungi Imperfecti)..Deuteromycetes

The Deuteromycetes is a form class for those fungi (with morphological affinities to the Ascomycetes or Basidiomycetes) which have not demonstrated a sexual stage. The generally employed classification scheme for these fungi is based on the morphology and color of the asexual reproductive stages. This scheme is briefly outlined below. Newer concepts of the classification based on conidium development after the classical work of S. J. Hughes (1953) may eventually replace the gross morphology system (see Barron 1968).

KEY TO THE FORM-ORDERS OF THE FUNGI IMPERFECTI

1 Reproduction by means of conidia, oidia, or by budding..2
1' No reproductive structures present..Mycelia Sterilia

2 (1) Reproduction by means of conidia borne in pycnidia..Sphaeropsidales
2' Conidia, when formed, not in cycnidia..3

3 (2') Conidia borne in acervuli..Melanconiales
3' Conidia borne otherwise, or reproduction by oidia or by budding..Moniliales

KEY TO THE FORM-FAMILIES OF THE MONILIALES

1 Reproduction mainly by unicellular budding, yeast-like; mycelial phase, if present, secondary, arthrospores occasionally produced, manifest melanin pigmentation lacking......2
1' Thallus mainly filamentous; dark melanin pigments sometimes produced..3

2 (1) Ballistospores produced..Sporobolomycetaceae
2' No ballistospores..Cryptococcaceae

3 Conidiophores, if present, not united into sporodochia or synnemats..4
3' Sporodochia present..Tuberculariaceae
3'' Synnemata present Stilbellaceae

4 (3) Conidia and conidiophores or oidia hyaline or brightly colored..Moniliaceae
4' Conidia and/or conidiophores, containing dark melanin pigment..Dematiaceae

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FRESHWATER POLLUTION ECOLOGY

Q.	WHAT IS ECOLOGY?
A.	The science of the interrelation between living organisms and their environment.
Q.	WHAT IS NOT ECOLOGY?
A.	Not much!

T. T. Macan

BIOLOGICAL ASPECTS OF NATURAL SELF PURIFICATION

I INTRODUCTION

A The results of natural self purification processes are readily observed. Did they not exist, sewage (and other organic wastes) would forever remain, and the world as we know it would long ago have become uninhabitable. Physical, chemical, and biological factors are involved. The microscopic and macroscopic animals and plants in a body of water receiving organic wastes are not only exposed to all of the various (ecological) conditions in that water, but they themselves create and profoundly modify certain of those conditions.

B Since toxic chemicals kill some of or all of the aquatic organisms, their presence disrupts the natural self purification processes, and hence, will not be considered here. The following discussion is based solely on the effects of organic pollution such as sewage or other readily oxidizable organic wastes.

C This description is based on the concept of a "stream" since under the circumstances of stream or river flow, the events and conditions occur in a linear succession. The same fundamental processes occur in lakes, estuaries, and oceans, except that the sequence of events may become telescoped or confused due to the reduction or variability of water movements.

D The particular biota (plants and animals, or flora and fauna) employed as illustrations below are typical of central United States. Similar or equivalent forms occur in similar circumstances in other parts of the world.

E This presentation is based on an unpublished chart produced by Dr. C.M. Tarzwell and his co-workers in 1951. Examples from this chart are employed in the presentation.

II THE STARTING POINT

A A normal unpolluted stream is assumed as a starting point. (Figure 1)

B The cycle of life is in reasonably stable balance.

C A great variety of life is present, but no one species or type predominates.

D The organisms present are adjusted to the normal ranges of physical and chemical factors characteristic of the region, such as the following:

1 The latitude, turbidity, typical cloud cover, etc. affect the amount of light penetration and hence photosynthesis.

2 The slope, cross sectional area, and nature of the bottom affect the rate of flow, and hence the type of organisms present deposition of sludge, etc.

3 The temperature affects both certain physical characteristics of the water, and the rate of biological activity (metabolism).

4 Dissolved substances naturally present in the water greatly affect living organisms (hard water vs. soft water fauna and flora).

E Clean water zones can usually be characterized as follows:

1 General features:

a Dissolved oxygen high

b BOD low

c Turbidity low

d Organic content low

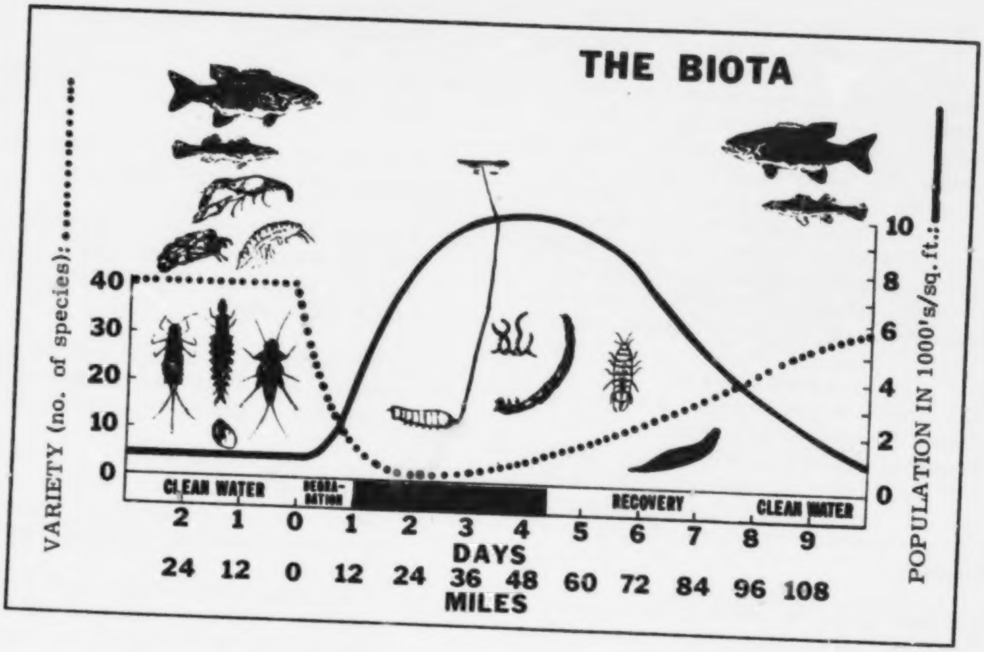

Figure 1: Relations between variety and abundance (production) of aquatic life, as organic pollution (discharged at mile 0) is carried down a stream. Time and distance scales are only relative and will be found to differ in nearly every case. After Bartsch and Ingram.[1]

e Bacterial count low

f Numbers of species high

g Numbers of organisms of each species moderate or low

h Bottom free of sludge deposits

2 Characteristic biota includes a wide variety of forms such as:

a A variety of algae and native higher (vascular, or rooted) plants

b Caddis fly larvae (Trichoptera)

c Mayfly larvae (Ephemeroptera)

d Stonefly larvae (Plecoptera)

e Damselfly larvae (Zygoptera)

f Beetles (Coleoptera)

g Clams (Pelecypoda)

h Fish such as:

- Minnows (Notropid types)
- Darters (Etheostomatidae)
- Millers thumb (Cottidae)
- Sunfishes and basses (Centrarchidae)
- Sauger, yellow perch, etc. (Percidae)
- Others

3 Organisms characteristic of clean lakes, estuaries, or oceanic shores might be substituted for the above, and likewise in the following sections. However, it should be recognized that no single habitat is as thoroughly understood in this regard as the freshwater stream.

III POLLUTION

A With the introduction of organic pollution (Figure 1, day 0), a succession of fairly well organized events are initiated. Important items to observe in interpreting the pollutional significance of stream organisms are the following:

B Numbers of species present, they tend to decrease with pollution.

C Numbers of individuals of each species tends to increase with pollution.

D Ratios between types of organisms are disturbed by pollution.

1 Clean water species intolerant of organic pollution tend to become scarce and unhealthy.

2 Animals with air breathing devices or habits tend to increase in numbers.

3 Scavengers become dominant

4 Predators disappear

5 Higher plants, green algae, and most diatoms tend to disappear.

6 Blue green algae often become conspicious

E The importance of observations on any single species is very slight.

IV THE ZONE OF RECENT POLLUTION

A The zone of recent pollution begins with the act of pollution, the introduction of excessive organic matter: food for microorganisms (Figure 1, day 0)

B There follows a period of physical mixing.

C Many animals and plants are smothered or shaded out by the suspended material.

D With this enormous new supply of food material, bacteria and other saprophytic microorganisms begin to increase rapidly.

E The elimination of intolerant predatory animals allows the larger scavengers to take full advantage of the situation.

F This explosive growth of organisms, particularly fungi and bacteria, draws heavily on the free dissolved oxygen for respiration, and may eventually eliminate it.

G The number of types of organisms diminishes but numbers of individuals of tolerant types may increase.

H Zone of degeneration, or recent pollution, can usually be characterized as follows:

1 General features:

a DO variable, 2 ppm to saturation

b BOD high

c Turbidity high

d Organic content high

e Bacterial count variable to high

f Number of species declines from clean water zone

g Number of organisms per species tends to increase

h Other: Slime may appear on bottom

2 Characteristic biota:

a Fewer higher plants, but rank heavy growth of those which persist

b Increase in tolerant green, and blue green algae

c Midge larvae (Chironomidae) may become extremely abundant

d Back swimmers (Corixidae) and water boatmen (Notonectidae) often present

e Sludge worms (Tubificidae) common to abundant.

f Dragonflies (Anisoptera) often present have unique tail breathing strainer

g Fish types, eg:

- Fathead minnows (Pimephales promelas)
- White sucker (Catostomus commersonni)
- Bowfin (Amia calva)
- Carp (Cyprinus carpio)

V THE SEPTIC ZONE

A The exact location of the beginning of the septic zone, if one occurs, varies with season and other circumstances. (Figure 1, day 1)

B Lack of free DO kills many microorganisms and nearly all larger plants and animals, again replenishing the mass of dead organic material.

C Varieties of both macro and micro-organisms and adjustable types (facultative) that can live in the absence of free oxygen (anaerobic) take over.

D These organisms continue to feed on their bonanza of food (pollution) until it is depleted.

E The numbers of types of organisms is now at a minimum, numbers of individuals may or may not be at a maximum.

F The septic zone, or zone of putrefaction can usually be characterized as follows:

1 General features:

a Little or no DO during warm weather

b BOD high but decreasing

c Turbidity high, dark; odoriferous

d Organic content high but decreasing

e Bacterial count high

f Number of species very low

g Number of organisms may be extremely high

h Other: Slime blanket and sludge deposits usually present, oily appearance on surface, rising gas bubbles

2 Characteristic biota:

a Blue green algae

b Mosquito larvae

c Rat-tailed maggots

d Sludge worms (Tubificidae and similar forms). Small, red, segmented (annelid) worms seem to be characteristic of this zone in both fresh and salt waters, the world around.

e Air breathing snails (Physa for example)

f Fish types: None

3 Note: Fortunately, all polluted waters do not always degenerate to "septic" conditions.

VI THE RECOVERY ZONE

A The septic zone gradually merges into the recovery zone. (Figure 1, day 4)

B As the excessive food reserves diminish so do the numbers of anaerobic organisms and other pollution tolerant forms.

C As the excessive demand for oxygen diminishes, free DO begins to appear and likewise oxygen requiring (aerobic) organisms.

D As the suspended material is reduced and available mineral materials increase due to microbial action, algae begin to increase often in great abundance.

E Photosynthesis by the algae releases more oxygen, thus hastening recovery.

F Since algae require oxygen at all times for respiration (like animals), heavy concentrations of algae will deplete free DO during the night when it is not being replenished by photosynthesis.

G Consequently this zone is characterized by extreme diurnal fluctuations in DO.

H With oxygen for respiration and algae, etc. for food, general animal growth is resumed.

I The stream may now enter a period of excessive productivity which lasts until the accumulated energy (food) reserves have been dissipated.

J Zone of recovery may usually be characterized as follows:

1 General features:

a DO 2 ppm to saturation

b BOD dropping

c Turbidity dropping, less color and odor

d Organic content dropping

e Bacterial count dropping

f Numbers of species increasing

g Numbers of organisms per species decreasing, (with the increase in competition)

h Other: Less slime and sludge

2 Characteristic biota

a Blue green algae

b Tolerant green flagellates and other algae

c Rooted higher plants in lower reaches

d Midge larve (Chironomids)

e Black fly larvae (Simulium)

f Giant water bugs (Belostoma spp.)

g Clams (Megalonais)

h Fish types:

- Green sunfish (Lepomis cyanellus)
- Common sucker (Catostomus commersonni)
- Flathead catfish (Pylodictis olivaris)
- Stoneroller minnow (Campostoma anomalum)
- Buffalo (Ictiobus cyprinellus)

3 Excessive production and extreme variability often characterize middle and lower recovery zones.

4 Unfortunately, many waters once polluted never completely "recover". Re-pollution is the rule in many areas so that after the initial pollution, clear out delineation of zones is not possible. Characterization of these waters may involve such parameters as productivity, BOD, some "index" figure, or other value not included here.

VII CLEAN WATER ZONE

A Clean water conditions again obtain when productivity has returned to a normal, relatively poor level, and a well balanced varied flora and fauna are present. (Figure 1, day "10") Conditions may usually be characterized as follows:

B General features: similar to upstream clean water except that it is now a larger stream.

C Characteristic biota: similar to upstream clean water fauna and flora except that species include those indigenous to a larger stream.

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ECOLOGY OF WASTE STABILIZATION PROCESSES

I INTRODUCTION

Living organisms will live where they can live. This holds for treatment plant environments just as it does for streams, impoundments, oceans, dry or wet lands.

A Each species has certain limits or tolerances, growth, feeding habits and other characteristics that determine its favored habitat.

B The presence of certain organisms with well defined characteristics in a viable condition and in significant numbers also provides some inference with respect to the habitat.

C The indicator organism concept has certain pitfalls. It is not sufficient to base an opinion upon one or more critters which may have been there as a result of gas liquid or solid transport. It is necessary to observe growth patterns, associated organisms, environmental conditions, and nutritional characteristics to provide information on environmental acceptability.

D Organisms characteristic of wastewater treatment commonly are those found in nature under low DO conditions. Performance characteristics are related to certain organism progressions and associations that are influenced by food to organism ratios and pertinent conditions. One single species is unlikely to perform all of the functions expected during waste treatment. Many associated organisms compete in an ecological system for a favored position. The combination includes synergistic, antagonistic, competitive, predative, and other relationships that may favor predominance of one group for a time and other groups under other conditions.

E It is the responsibility of the treatment plant control team to manage conditions of treatment to favor the best attainable performance during each hour of the day each day of the year. This outline considers certain biological characteristics and their implications with respect to treatment performance.

II TREATMENT PLANT ORGANISMS

Wastewater is characterized by overfertilization from the standpoint of nutritional elements, by varying amounts of items that may not enter the metabolic pattern but have some effect upon it, such as silt, and by materials that will interfere with metabolic patterns. Components vary in availability from those that are readily acceptable to those that persist for long periods of time. Each item has some effect upon the organism response to the mixture.

A Slime forming organisms including certain bacteria, fungi, yeasts; protista monera and alga tend to grow rapidly on dissolved nutrients under favorable conditions. These grow rapidly enough to dominate the overall population during early stages of growth. There may be tremendous numbers of relatively few species until available nutrients have been converted to cell mass or other limiting factors check the population explosion.

B Abundant slime growth favors production of predator organisms such as amoeba or flagellates. These feed upon preformed cell mass. Amoebas tend to flow around particulate materials; flagellates also are relatively inefficient food gatherers. They tend to become numerous when the nutrient level is high. They are likely to be associated with floculated masses where food is more abundant.

C Ciliated organisms are more efficient food gatherers because they have the ability to move more readily and may set up currents in the water to bring food to them for ingestion. Stalked ciliates are implicated with well stabilized effluents because they are capable of sweeping the fine particulates from the water between floc masses while their residues tend to become associated with the floc.

D Larger organisms tend to become established later and serve as scavengers. These include Oligochaetes (worms), Chironomids (bloodworms and insect larvae), Isopods (sow bugs and crustacea), Rotifera and others.

III TREATMENT OPERATIONAL CONTROL

An established treatment plant is likely to contain representative organisms from all groups of tolerant species. Trickling filters, activated sludge, or ponds tend to retain previously developed organisms in large numbers relative to the incoming feed. The number and variety available determine the nature, degree and time required for partial oxidation and conversion of pollutants from liquid to solid concentrates.

A Proliferation of slime forming organisms characterize the new unit because they grow rapidly on soluble nutrients. Predators and scavengers may start growing as soon as cell mass particulates appear but growth rate is slower and numbers and mass lag as compared with slime organisms. As slime growth slows due to conversion of soluble nutrients to cell mass, the slime formers tend to associate as agglomerates or clumps promoting floculation and liquid solid separation.

B Overfeeding an established unit encourages rapid growth of slime organisms as individual cells rather than as flocculated masses. This results in certain characteristics resembling those of a young, rapidly growing system.

C Toxic feeds or unfavorable conditions materially reduce the population of exposed sensitive organisms. The net effect is a population selection requiring rapid regrowth to reestablish desired operating characteristics. The system assumes new growth characteristics to a degree depending upon the fraction remaining after the toxic effect has been relieved by dilution, degradation, sorption, or other means.

D Treatment units are characterized by changes in response to feed sequence, load ratio, and physical or chemical conditions. Response to accute toxicity may be immediately apparent. Chronic overloading or mild toxicity may not be apparent for several days. It may be expected that it will require 1 to 3 weeks to restore effective performance after any major upset. Performance criteria may not indicate a smooth progression toward improved operation.

E Observations of the growth characteristics and populations do not provide quantitative information, but they do indicate trends and stages of development that are useful to identify problems. It is not possible to identify most slime organisms by direct observation. It is possible to recognize growth and flocculation characteristics. Certain larger organisms are recognizable and are useful as indicator organisms to suggest past or subsequent developments.

IV ILLUSTRATIONS OF ECOLOGICAL SIGNIFICANCE

A The first group represents initial development of non-flocculent growth. Single celled and filamentous growth are shown. Rapid growth shows little evidence of flocculation that is necessary to produce a stable, clear effluent.

B The next group of slides indicate development of floc forming tendencies from filamentous or non-filamentous growth. Clarification and compaction characteristics are relatable to the nature and density of floc masses.

C Organisms likely to be associated with more stabilized sludges are shown in the third group. Scavengers essentially consist of a large alimentary canal with accessories.

D The last two slides illustrate changes in appearance after a toxic load. Scavengers, ciliates, etc. have been inactivated. New growth at the edge of the floc masses are not apparent. Physical structure indicates dispersed residue rather than agglomeration tendencies. The floc probably contains living organisms protected by the surrounding organic material, but only time and regrowth will reestablish a working floc with good stabilization and clarification tendencies.

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THE INTERPRETATION OF BIOLOGICAL DATA WITH REFERENCE TO WATER QUALITY

I INTRODUCTION

Sanitary engineers like to have data presented to them in a readily assimilable form and some of them seem a little impatient with biologists who appear unable to provide definite quantitative criteria applicable to all kinds of water conditions. I think the feeling tends to be that this is the fault of biologists, and if they would only pull themselves out of the scientific stone-age all would be well. I will try to explain here why I believe that biological data can never be absolute nor interpretable without a certain amount of expertise. In this respect biologists resemble medical men who make their diagnoses against a complex background of detailed knowledge. Anyone can diagnose an open wound but it takes a doctor to identify an obscure disease; and although he can explain how he does it he cannot pass on his knowledge in that one explanation. Similarly, one does not need an expert to recognize gross organic pollution, but only a biologist can interpret more subtle biological conditions in a water body; and here again he can explain how he does it, but that does not make his hearer a biologist. Beck (1957) said something similar at a previous symposium in Cincinnati in 1956.

II THE COMPLEXITY OF BIOLOGICAL REACTIONS TO WATER CONDITIONS

A Complexity of the Aquatic Habitat

The aquatic habitat is complex and consists not only of water but of the substrata beneath it, which may be only indirectly influenced by the quality of the water. Moreover, in biological terms, water quality includes such features as rate of flow and temperature regime, which are not considered of direct importance by the chemist. To many animals and plants, maximum summer temperature or maximum rate of flow is just as important as minimum oxygen tension. The result is that inland waters provide an enormous array of different combinations of conditions, each of which has its own community of plants and animals; and the variety of species involved is very great. Thus, for example, Germany has about 6000 species of aquatic animals (Illies 1961a) and probably at least as many species of plants. Yet Europe has a rather restricted fauna because of the Pleistocene ice age; in most other parts of the world the flora and fauna are even richer.

B Distribution of Species and Environmental Factors

We know something about the way in which species are distributed in the various habitats, especially in the relatively much studied continent of Europe, but we have, as yet, little idea as to what factors or combination of factors actually control the individual species.

1 Important ecological factors

Thus, it is possible to list the groups of organisms that occur in swift stony upland rivers (rhithron in the sense of Illies, 1961b) and to contrast them with those of the lower sluggish reaches (potamon). Similarly we know, more or less, the different floras and faunas we can expect in infertile (oligotrophic) and fertile (eutrophic) lakes. We are, however, much less informed as to just what ecological factors cause these differences. We know they include temperature and its yearly amplitude; oxygen, particularly at minimal levels; plant nutrients, such as nitrate, phosphate, silica, and bicarbonate; other ions in solution, including calcium, chloride, and possibly hydrogen; dissolved organic matter, which is necessary for some bacteria and fungi and probably for some algae; the nature of the substratum; and current.

2 Complexity of interacting factors

We also know these factors can interact in a complex manner and that their action on any particular organism can be indirect through other members of the biota.

a Induced periphyton growths

Heavy growths of encrusting algae induced by large amounts of plant nutrients, or of bacteria induced by ample supplies of organic matter, can eliminate or decimate populations of lithophile insects by simple mechanical interference. But the change does not stop there: the growths themselves provide habitats for the animals, such as Chironomidae and Naidid worms, which could not otherwise live on the stones.

b Oxygen levels and depositing substrates

If oxygen conditions over a muddy bottom reach levels just low enough to be intolerable to leeches, tubificid worms, which the leeches normally hold in check, are able to build up to enormous numbers especially as some of their competitors (e.g. Chironomus) are also eliminated.

c Oxygen levels and non muddy substrates

One then finds the typical outburst of sludge worms, so often cited as indicators of pollution. This does not happen if the same oxygen tension occurs over sand or rock, however, as these are not suitable substrata for the worms. Many such examples could be given, but they would only be ones we understand; there must be a far greater number about which we know nothing.

d One must conclude, therefore, that quite simple chemical changes can produce far-reaching biological effects; that we only understand a small proportion of them; and that they are not always the same.

3 Classic examples

This seems like a note of despair, however, if water quality deviates too far from normal, the effects are immediately apparent. Thus, poisonous substances eliminate many species and may leave no animals (Hynes 1960); excessive quantities of salt remove all leeches, amphipods, and most insects and leave a fauna consisting largely of Chironomidae, caddis worms, and oligochaetes (Albrecht 1954) and excessive amounts of dissolved organic matter give rise to carpets of sewage fungus, which never occur naturally. Here no great biological expertise is needed, and there is little difficulty in the communication of results. It is when effects are slighter and more subtle that biological findings become difficult to transmit intelligibly to other disciplines.

III THE PROBLEMS IN PRESENTATION OF BIOLOGICAL RESULTS

Because of these difficulties various attempts have been made to simplify the presentation of biological findings, but to my mind none of them is very successful because of the complexity of the subject. Early attempts at systematization developed almost independently on the two sides of the Atlantic, although they had some similarities.

A Early Studies in the United States (Richardson and the Illinois River)

In America, there was a simple division into zones of pollution, e.g. degradation, septic, and recovery, which were characterized in broad general terms. This simple, textbook approach is summarized by Whipple et al. (1947), and serves fairly well for categorizing gross organic pollution such as has been mentioned above. It was, however, soon found by Richardson (1929) during his classical studies on the Illinois River that typical "indicators" of foul conditions, such as Tubificidae and Chironomus, were not always present where they would be expected to occur. This was an early indication that it is not the water quality itself that provides suitable conditions for "pollution faunas," but other, usually associated, conditions - in this instance deposits of rich organic mud. Such conditions may, in fact, be present in places where water quality in no way resembles pollution, e.g., upstream of weirs in trout streams where autumn leaves accumulate and decay and cause the development of biota typical of organically polluted water. Samples must therefore be judged against a background of biological knowledge. Richardson was fully aware of this and was in no doubt about the condition of the Illinois River even in places where his samples showed few or no pollution indicators.

B The European Saprobic System

In Europe, the initial stress was primarily on microorganisms and results were first codified in the early years of the century by Kolkwitz and Marsson. In this "Saprobiensystem," zones of organic pollution similar to those described by the American workers were defined and organisms were listed as characteristic of one or more zones;

TABLE 1

SAPROBIENSYSTEM - A European system of classifying organisms according to their response to the organic pollution in slow moving streams. (22)

Alpha-Mesosaprobic Zone - Area of active decomposition, partly aerobic, partly anaerobic, in a stream heavily polluted with organic wastes.

Beta-Mesosaprobic Zone - That reach of stream that is moderately polluted with organic wastes.

Oligosaprobic Zone - That reach of a stream that is slightly polluted with organic wastes and contains the mineralized products of self-purification from organic pollution, but with none of the organic pollutants remaining.

Polysaprobic Zone - That area of a grossly polluted stream which contains the complex organic wastes that are decomposing primarily by anaerobic processes.

A recent exposition of this list is given by Kolkwitz (1950). It was then claimed that with a list of the species occurring at a particular point it was possible to allocate it to a saprobic zone. This system early met with criticism for several reasons. First,

TABLE 2

SAPROBICITY LEVELS ACCORDING TO THE TROPHIC STRUCTURE OF THE COMMUNITIES OF ORGANISMS

Saprobicity Level	Structure of the Communities of Organisms
I β-oligosaprobic	Balanced relationship between producers, consumers and destroyers; the communities of organisms are poor in individuals but there is a moderate variety of species, small biomass and low bioactivity.
II α-oligosaprobic	Balanced relationship between producers, consumers and destroyers; communities of organisms are rich in individuals and species with a large biomass and high bioactivity.
III β-mesosaprobic	Substantially balanced relationship between producers, consumers and destroyers; a relative increase in the abundance of destroyers and, accordingly, of the consumers living off them; communities of organisms are rich in individuals and species with a large biomass and high bioactivity.
IV α-mesosaprobic	Producers decline as compared with an increase in consumers and destroyers; mixotrophic and amphitrophic forms predominate among the producers; communities of organisms rich in individuals but poor in species with a large biomass and extremely high bioactivity; still only few species of macro-organisms; mass development of bacteria and bacteria-eating ciliates.
V β-polysaprobic	Producers drastically decline; communities of organisms are extremely rich in individuals but poor in species with a large biomass and high bioactivity; macrofauna represented only by a few species of tubificids and chironomids; as in IV these are in great abundance; mass development of bacteria and bacteria-eating ciliates.
VI α-polysaprobic	Producers are absent; the total biomass is formed practically solely by anaerobic bacteria and fungi; macro-organisms are absent; flagellates outnumber ciliates amongst the protozoa.

Saprobicity - "Within the bioactivity of a body of water, Saprobicity is the sum total of all those metabolic processes which are the antithesis of primary production. It is therefore the sum total of all those processes which are accompanied by a loss of potential energy." Part I, Prague Convention.

all the organisms listed occurred in natural habitats--they were not evolved in polluted water--and there was much doubt as to the placing of many of the species in the lists. The system, however, did serve to codify ecological knowledge about a long list of species along an extended trophic scale. Its weaknesses appeared to be merely due to lack of knowledge; such a rigid system took far too little account of the complexity of the reaction of organisms to their habitats. For instance, many organisms can be found, albeit rarely, in a wide range of conditions and others may occur in restricted zones for reasons that have nothing to do with water quality. We often do not know if organisms confined to clean headwaters are kept there by high oxygen content, low summer temperatures, or inability to compete with other species under other conditions. In the swift waters of Switzerland the system broke down in that some organisms appeared in more polluted zones than their position in the lists would indicate. Presumably here the controlling factor was oxygen, which was relatively plentiful in turbulent cold water. In a recent series of experiments, Zimmerman (1962) has proven that current alone has a great influence on the biota, and identically polluted water flowing at different speeds produces biotic communities characteristic of different saprobic levels. He finds this surprising, but to me it seems an expected result, for the reasons given above.

C Recent Advances in the Saprobic System

1 Perhaps Zimmerman's surprise reflects the deeply rooted entrenchment of the Saprobiensystem in Central Europe. Despite its obvious shortcomings it has been revised and extended. Liebmann (1951) introduced the concept of considering number as well as occurrence and very rightly pointed out that the community of organisms is what matters rather than mere species lists. But he did not stress the importance of extrinsic factors, such as current, nor that the system can only apply to organic pollution and that different types of organic pollution differ in their effects; e.g., carbohydrate solutions from paper works produce different results from those of sewage, as they contain little nitrogen and very different suspended solids. Other workers (Sladecek 1961 and references therein) have subdivided the more polluted zones, which now, instead of being merely descriptive, are considered to represent definite ranges of oxygen content, BOD, sulfide, and even E. coli populations. Every water chemist knows that BOD and oxygen content are not directly related and to assume that either should be more than vaguely related to the complexities of biological reactions seems to me to indicate a fundamental lack of ecological understanding. I also think it is damaging to the hope of mutual understanding between the various disciplines concerned with water quality to give the impression that one can expect to find a close and rigid relationship between water quality measurements as assessed by different sets of parameters. Inevitably these relationships vary with local conditions; what applies in a sluggish river in summer will certainly not apply to a mountain stream or even to the same river in the winter. Correlation of data, even within one discipline, needs understanding, knowledge, and judgment.

2 Caspers and Schulz (1960) showed that the failure of the system to distinguish between waters that are naturally productive and those artifically enriched can lead to absurd results. They studied a canal in Hamburg, which because of its urban situation can only be regarded as grossly polluted. Yet it develops a rich plankton,

the composition of which, according to the system, shows it to be virtually clean.

D Numerical Application of the Saprobic System

Once the Saprobiensystem was accepted it was logical to attempt to reduce its findings to simple figures or graphs for presentation of results. Several such methods were developed, which are described by Tumpling (1960), who also gives the original references. In all these methods, the abundance of each species is recorded on some sort of logarithmic scale (e.g. 1 for present, 3 for frequent, 5 for common, etc.). The sums of these abundances in each saprobic level are plotted on graphs, the two most polluted zones showing as negative and others as positive. Or, the various saprobic levels are given numerical values [1 for oligosaprobic (clean), 2 for β-mesosaprobic, etc.] and the rating for each species is multiplied by its abundance number. The sum of all these products divided by the sum of all the frequencies gives a "saprobic index" for the locality. Clearly the higher this number, the worse the water quality in terms of organic pollution. In a similar way the so-called "relative Belastung" (relative load) is calculated by expressing the sums of all the abundances of organisms characteristic of the two most-polluted zones as a percentage of the sum of all abundances. Then 100 percent is completely polluted water, and clean localities will give a low number.

E Weaknesses of the Saprobic System

There are various elaborations of these methods, such as sharing of species between zones and taking account of changes in base-line as one passes downstream. None of them, however, eliminates the basic weaknesses of the system nor the fact that, as Caspers and Schulz (1960) point out, there is little agreement between the various authors in the assignment of species to the different levels. Therefore, one gains a number or a figure that looks precise and is easily understood, but it is based on very dubious foundations.

F Comparative North American Systems

Similar systems are indigenous to North America, but were independently evolved.

1 Wurtz (1955) and Wurtz and Dolan (1960) describe a system whereby animals are divided into sensitive-to-pollution and non-sensitive (others are ignored), and also into burrowing, sessile, and foraging species (six classes). Numbers of these species represented are plotted for each station as six histograms on the basis of percentage of total number of species. If the constitution of the fauna from control stations or from similar localities is known, it is possible to express numerically "biological depression" (i.e., percentage reduction in total

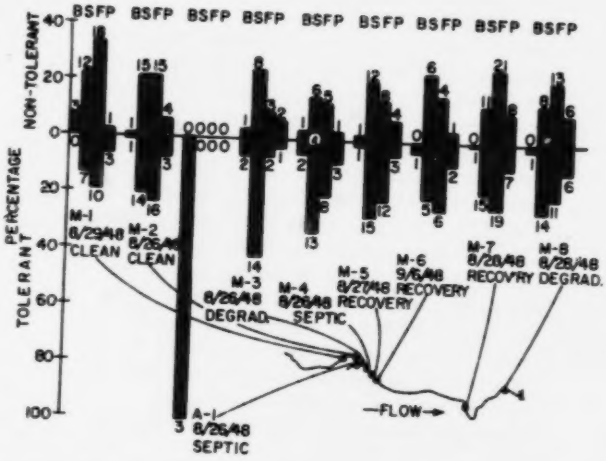

Figure 1. Histograms, based on selected organisms, illustrating stream reaches of clean, degradation, septic, and recovery conditions [after Wurtz] (22)

number of species), "biological distortion" (changes in proportions of tolerant and non-tolerant species), and "biological skewness" (changes in the ratios of the three habitat classes). Such results must, of course, be evaluated, and the definition of tolerance is quite subjective; but the method has the advantages of simplicity and dependence on control data. Like the Saprobiensystem, however, it can have no universal validity. It also suffers from the fact that it takes no account of numbers; a single specimen, which may be there by accident, carries as much weight as a dense population.

2 Patrick (1949) developed a similar system in which several clean stations on the water body being investigated are chosen, and the average number of species is determined occurring in each of seven groups of taxa chosen because of their supposed reaction to pollution. These are then plotted as seven columns of equal height, and data from other stations are plotted on the same scale; it is assumed that stations differing markedly from the controls will show biological imbalance in that the columns will be of very unequal heights. Number is indicated by double width in any column containing species with an unusual number of individuals.

I have already questioned the usefulness of this method of presentation (Hynes 1960), and doubt whether it gives any more readily assimilable data than simple tabulation; it does however, introduce the concept of ecological imbalance.

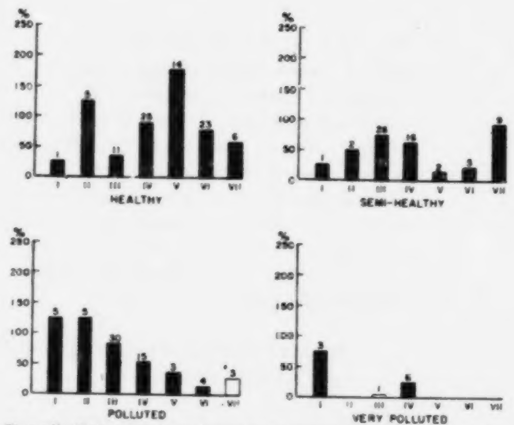

Figure 2. Histograms, based on selected organisms, illustrating healthy, semi-healthy polluted, and very polluted stations in Conestoga Basin, Pa. [after Patrick] (22)

TABLE 3 **—Classification of Groups of Organisms Shown in Figure** 2

GROUP	ORGANISM
I	Blue-green algae; green algae of the genera *Stigeoclonium*, *Spirogyra*, and *Tribonema*, the bdelloid rotifers plus *Cephalodella megalocephala* and *Proales decipiens*
II	Oligochaetes, leeches, and pulmonate snails
III	Protozoa
IV	Diatoms, red algae, and "most of the green algae"
V	All rotifers not included in Group I, clams, gill-breathing snails, and tricladid flatworms
VI	All insects and crustacea
VII	All fish

3 Beak (1964), another author, recognized the need for a concise expression of pollution based on biological information. Toward this end, he developed a method of biological scoring which is based on the frequency of occurrence of certain macroscopic invertebrates obtained from 6 years of study on one river. It will be noted that the Biological Score is a modification and expansion of Beck's Biotic Index.

The indicator organisms are divided into three categories: Group I contains the pollution-tolerant species; Group II comprises those species which are facultative with respect to pollution; and Group III contains the pollution-intolerant forms. Each group is assigned a weighted score that can be allotted to field samples on the following basis:

a Normal complement of Group III scores 3 points.

b Normal complement of Group II scores 2 points.

c Normal complement of Group I scores 1 point.

The scores are additive; thus an unpolluted stream will have a Biological Score of 6. If only pollution-tolerant forms are found, the score will be 1. If no organisms are found, the score will be zero. Furthermore, a score of, 1 or 2 points could be allotted to Group III when less than the normal complement is present. Group II could be treated in a similar manner. This scoring device correlated well with the biological oxygen demand, dissolved oxygen, and solids content of the receiving water. Beak also related his scoring device to the fisheries potential. This relationship is shown in Table 4]

TABLE 4

TENTATIVE RELATIONSHIP OF THE BIOLOGICAL SCORE TO THE FISHERIES POTENTIAL (after Beak, 1964) (30)

Pollution status	Biotic index	Fisheries potential
Unpolluted	6	All normal fisheries for type of water well developed
Slight to moderate pollution	5 or 4	Most sensitive fish species reduced in numbers or missing
Moderate pollution	3	Only coarse fisheries maintained
Moderate to heavy pollution	2	If fish present, only those with high toleration of pollution
Heavy pollution	1	Very little, if any, fishery
Severe pollution, usually toxic	0	No fish

4 It has long been known that ecologically severe habitats contain fewer species than normal habitats and that the few species that can survive the severe conditions are often very abundant as they lack competitors. Examples of this are the countless millions of Artemia and Ephydra in saline lakes and the Tubifex tubifex in foul mud. This idea has often been expressed in terms of diversity, which is some measure of numbers of species divided by number of specimens collected. Clearly, such a parameter is larger the greater the diversity, and hence the normality of the habitat. Unfortunately, though as the number of species in any habitat is fixed, it also decreases as sample size increases so no index of diversity has any absolute value (Hairston 1959). If a definite sample size is fixed, however, in respect to numbers of organisms identified, it is possible to arrive at a constant index.

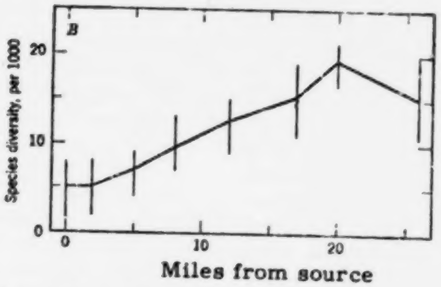

Figure 3. Zooplankton species diversity per thousand individuals encountered in marine systems affected by waste waters from petrochemical industrial wastes. The vertical lines indicate seasonal variations. (30)

5 Patrick et al. (1954) in effect used this concept in a study of diatom species growing on slides suspended in water for fixed periods. They identified 8000 specimens per sample and plotted the results as number of species per interval against number of specimens per species on a logarithmic scale. This method of plotting gives a truncated normal curve for a wide variety of biotic communities. In an ordinarily diverse habitat the mode is high and the curve short; i.e., many species occur in small numbers and none is very abundant. In a severe habitat the mode is low and the curve long; i.e., there are few rare species and a few with large numbers. This, again, seems to me to be an elaborate way of presenting data and to involve a lot of unnecessary arithmetic.

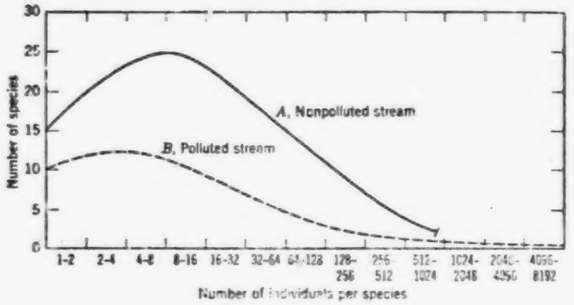

Figure 4. A graphic comparison of diatom communities from two different environments. (After Patrick et al., 1954) (30)

6 Diversity indices vs tabulated data

Allanson (1961) has applied this method to the invertebrate faunas of streams in South Africa and has shown, as has Patrick for diatoms, that the log normal curve is flatter and longer for polluted stations; the difference, however, is not so apparent that it does not need exposition. Here, again, I would suggest that tabulated data are just as informative. Indeed I would go further and say that tabulated data are essential in the present state of our knowledge. We are learning as we go along and if the details of the basic findings are concealed by some sort of arithmetical manipulation they cannot be re-interpreted in the light of later knowledge, nor are they preserved in the store of human knowledge. This point becomes particularly clear when one examines some of the early studies that include tables. Butcher (1946) requotes a considerable amount of data he collected from studies of various English rivers during the thirties; they are not only clear and easy to follow, but they are also informative about the generalities of pollution in a way that data quoted only within the confines of some particular system are not.

7 Examples of tabulated data(Table 5)

Simple tabulation of biological data in relation to water quality, either in terms of number of organisms, percentage composition of the biota, some arbitrary abundance scale, or as histograms, has been effectively practiced in many parts of the world: in America (Gaufin and Tarzwell 1952, Gaufin 1958), Africa (Harrison 1958 and 1960, Hynes and Williams 1962), Europe (Albrecht 1954, Kaiser 1951, Hynes 1961, Hynes and Roberts 1962), and New Zealand (Hirsch 1958) to cite a few. These tabulated data are easy to follow, are informative to the expert reader, and conceal no facts. Although the non-biologist may find them tedious, he need only read the explanatory paragraphs. It is a delusion to think that it is possible to reduce biological data to simple numerical levels. At best, these can only be produced for limited situations and

TABLE 5

	1			2			3		
	206.3 power line			205.3			203.3		
ORGANISMS	left	mid	right	left	mid	right	left	mid	right
Zoothamnium	F								
Dendrosoma	C								F
Spongilla fragilis								A	
Trochospongilla leidyi	C			C					
Unidentified Sponge					F			A	
Cordylophora lacustris		F		F	A	A			
Dugesia tigrina	5		2	4	4	6	14		19
Urnatella gracilis	C	C	C	C	F		F		F
Paludicella articulata	C			[illegible]	F	F	F		F
Fredericella sultana	C								
Pristina							1		
Nais communis				1		1		7	
Paranais									
Unidentified Leech									1
Unidentified Beetle			1						
Chaoborus punctipennis					1				
Hydrobaenus sp. A	31	47	5	9	117	68	1	26	4
Cricotopus bicinctus						1			
Unidentified Tendipedini								1	
Harnischia sp. A		5	2		29	2	1	8	
Tendipes nervosus	1				4	15		2	1
Tendipes modestus	59	14	16	7	12	7	1		3
Polypedilum sp. B									1
Calopsectra exigua			2	5	3	48	1	169	101
Trycorythodes	1			1			1		1
Stenonema				1					
Agraylea			2				1		
Athripsodes				2					
Potamyia flava				41		44	19	131	234
Hydropsyche orris				141		17	2	3	11
Cheumatopsyche		1		4	5	43		30	13
Psychomyiidae Genus A	51	22	21	30	54	92	11	193	21
Lithasia verrucosa									1
Ferrissia shimekii				4		33	7	[illegible]	19
Quadrula sp.						1	1		
Quadrula tuberculata						2			
Corbicula fluminea	4	1	5	11		1	77		[illegible]
TOTAL	152	90	56	261	229	381	141	575	437
	298			871			1,153		

F - few C - common A - abundant

Benthos from Pickwick Tailwater (35)

even then they need verbal exposition; at worst, they give a spurious impression of having absolute validity.

8 Comparison of stations

My final point in this section concerns comparisons. It is claimed that the German system, in effect, measures an absolute state, a definite level of water quality. We have seen that this is not a tenable claim. In the other systems, by and large, the need to establish local control stations at which to measure the normal or "natural" biotic conditions is accepted, and then other areas are compared with this supposed norm. This is, of course not always possible as there may remain no unaffected area, or no unaffected area that is, with respect to such factors as current, nature of substratum, etc., sufficiently similar to act as a base-line for data. Nevertheless, basically, these systems can be used to compare stations and thus to assess changes in water quality. In doing this, they can all be used more or less successfully, but I maintain that a table is just as useful as an elaborate analysis, and I believe that the table should be included with whatever is done. For a particular situation, however, it is often possible to distill the data into a single figure as a measure of similarity between stations.

9 Coefficients of similarity

Burlington (1962) and Dean and Burlington (1963) have recently proposed an entirely objective means of doing this, which involves simple arithmetical manipulation. In his system, a "prominence value" is calculated for each species at each station. This is a product of its density and some function of its frequency in samples, but the details of this calculation can be altered to suit any particular situation. Then a coefficient of similarity between each pair of stations can be calculated by dividing twice the sum of the lower prominence values of taxa that the two stations have in common by the sum of all the prominence values of both stations. Identical stations will then have a coefficient of similarity of 1:00; this coefficient will be lower the more the stations differ from one another. This is an easy way to compare stations in an entirely unbiased way and as such may satisfy the need for numerical exposition; however, it tells one nothing about why the localities are different and like all the other more or less numerical methods of presenting data has no absolute value. Moreover, it still leaves unanswered the fundamental question of how different is "different?"

TABLE 6

Clean

WATER QUALITY (high multiple use indicated)

Organisms in Order of Tendency to Disappear as Degree of Pollution Increases

Polluted

Types of Organisms Present	BIOTIC INDEX[1] Variety Present	✓Total Number of Groups Present 0-1	 2-5	 6-10	 11-15	 16+
Plecoptera nymph present	More than one species	--	Bio 7	Index 8	9	10
	One species only	--	6	7	8	9
Ephemeroptera nymph present	More than one species*	--	6	7	8	9✱
	One species only*	--	5	6	7	8
Trichoptera larvae present	More than one species•	--	5	6	7	8
	One species only•	4	4	5	6	7
Gammaridae present	All above species absent	3	4	5	6	7
Asellus and/or Lirceus present	All above species absent	2	3	4	5	6
Tubificid worms, Tendipes, and Cricotopus bicinctus (one or more of these groups)	All above species absent	1	2	3	4	--
All above types absent	Some organisms such as Eristalis tenax not requiring dissolved oxygen may be present	0	1	2	--	--

*Stenonema nepotellum excluded

10✱ main stream reservoirs and west Tennessee streams

• Stenonema nepotellum (Ephem.) is counted in this section for the purpose of classification.

✓ ONE FOR EACH KNOWN SPECIES IN THESE GROUPS:

- Platyhelminthes
- Hirudinea
- Mollusca
- Crustacea
- Plecoptera
- Diptera (excluding specific ones listed below)
- Coleoptera
- Neuroptera

✓ ONE FOR EACH GROUP, REGARDLESS OF NUMBER OF SPECIES, ETC.:

- Annelida excluding Naididae
- Naididae
- Each Mayfly genera (excluding Stenonema nepotellum)
- Stenonema nepotellum
- Each Trichoptera family
- Chironomidae (excluding specific ones listed below)
- Chironomus riparius and plumosus and Cricotopus bicinctus.
- Family Simuliidae

---

[1] adapted from Trent River Board - Tennessee Stream Pollution Control Board 8/66 RMS

IV THE PROBLEMS OF SAMPLING

The systems outlined above are all based on the assumption that it is possible to sample an aquatic habitat with some degree of accuracy; this is a dubious assumption, however, when applied to biological data. From what has been said about the complexity of biological reactions to the various factors in the environment, and from the obvious fact that rivers especially are a mosaic of microhabitats, it is clear that to achieve numerical accuracy or even some limits of confidence considerable numbers of samples need to be taken. Indeed, even in so apparently unvaried a habitat as a single riffle, Needham and Usinger (1956) showed that a very large number of samples would be necessary to give significant numerical data.

A Representative Sampling

There is a limit to the number of samples that can reasonably be taken and, anyway, it is desirable to sample many different types of habitat so as to get as broad as possible an estimate of the biota. This is the more recent approach of most of the workers in Central Europe, who have been content to cite abundances on a simple relative but arbitrary scale and to convert this to figures on some sort of logarithmic scale for use in calculations. An alternative is to express the catch in terms of percentage composition, but this had the disadvantage that micro- and macro-organisms cannot be expressed on the same scale as they are obtained by different collecting techniques. Also, of course, implicit in this approach is the assumption that the sampling is reasonably representative. Here again we run into the need for knowledge and expertise. In collection as well as in interpretation, the expert is essential. Biological sampling, unlike the simple, or fairly simple, filling of bottles for chemical analysis or the monitoring of measuring equipment, is a highly skilled job and not one to be handed over to a couple of vacationing undergraduates who are sent out with a Surber sampler and told to get on with it. This point has also been made by other biologists, e.g., Patrick (1961) who stresses the need for skilled and thorough collecting even for the determination of a species list.

B Non-Taxonomic Techniques

Alternatively we can use the less expert man when concentrating on only part of the habitat, using, say, microscopical slides suspended in the water to study algal growth. This method was extensively used by Butcher (1946), and Patrick et al. (1954) who studied diatoms in this way. This gives only a partial biological picture, but is useful as a means of monitoring a stretch of water where it is possible that changes might occur. It is a useful short-hand method, and as such is perhaps comparable to studying the oxygen absorbed from potassium permanganate instead of carrying out all the usual chemical analyses on water. A short method of this kind may serve very well most of the time, but, for instance, would not be likely to detect an insecticide in concentrations that could entirely eliminate arthropods and hence fishes by starvation.

C Monitoring

It is possible to work out biological monitoring systems for any specific purpose. The simplest of these is the cage of fish, which, like a single type of chemical analysis, can be expected to monitor only one thing — the ability of fish to live in the water — with no information on whether they can breed or whether there is anything for them to eat. Beak et al. (1959) describes a neat way in which the common constituents of the bottom fauna of Lake Ontario can be used to monitor the effluents from an industrial site. Obviously there is much room for such ingenuity in devising biological systems for particular conditions, but this is perhaps outside the scope of this meeting.

V CONCLUSIONS

It may appear from the previous sections that my attitude to this problem is entirely obstructionist. This is far from being so. Water quality is as much biological phenomenon as it is a chemical or physical one; often what we want to know about water is almost exclusively biological -- will it smell nasty, is it fit to drink, can one bathe in it, etc? I suggest, therefore, that it is desirable to organize water monitoring programs that will tell one what one wants to know. There is no point in measuring everything biological, just as there is no point in performing every possible chemical analysis; what is measured should be related to local conditions. It would be a waste of time to measure oxygen content in a clean mountain stream; we know it to be high, and it becomes worth measuring only if we suspect that it may have been lowered by pollution. Similarly, there is little point in studying the plankton in such a stream; we know it only reflects the benthic flora. In a lake or in a slow river, on the other hand, if our interest in the water lies in its potability, records of the plankton are of considerable importance as changes in plankton are, in fact, changes in the usability of the water.

A Periphyton and Benthos Studies

For long-term studies, especially for the recording of trends or changes induced by pollution, altered drainage, agricultural poisons, and other havoc wrought by man, one can expect informative results from two principal techniques: First, we can study microscopic plant and animal growth with glass slides placed in the water for fixed periods; second, we can obtain random samples of the benthic fauna. The algae and associated microfauna tell one a good deal about the nutrient condition of the water and the changes that occur in it, and the larger benthic fauna reveal changes in the trophic status, siltation due to soil erosion, effects of insecticides and other poisons, etc.

B Varying Levels of Complexity

The study of growths on glass slides is reasonably skilled work, but can easily be taught to technicians; like chemical monitoring, such study needs to be done fairly often. Sampling the benthos is more difficult and, as explained above, needs expert handling; unlike most other monitoring programs, however, it need be done only infrequently, say, once or twice a year. Inevitably sampling methods will vary with type of habitat; in each case, the question will arise as to whether it is worth looking at the fish also. It is here that the biologist must exercise judgment in devising and carrying out the sampling program.

C Data Interpretation

Judgment is also needed in the interpretation of the data. It is for this reason I maintain that it should all be tabulated so that it remains available for reassessment or comparison with later surveys. If need be, some sort of numerical format can be prepared from the data for ad hoc uses, but it should never become a substitute for tabulations. Only in this way can we go on building up our knowledge. Perhaps some day we shall be able to pass all this information into a computer, which will then be able to exercise better judgment than the biologist. I hope this will happen, as computers are better able to remember and to cope with complexity than men. It will not, however, pension off the biologist. He will still be needed to collect and identify the samples. I cannot imagine any computer wading about on rocky riffles nor persuading outboard motors and mechanical grabs to operate from the unstable confines of small boats. We shall still need flesh and blood biologists long after the advent of the hardware water chemist, even though, with reference to my earlier analogy, a Tokyo University computer recently outpointed 10 veteran medicals in diagnosing brain tumors and heart disease. It should be pointed out, however, that the computer still had to be fed with information, so we are still a long way from the hardware general practitioner. I believe though that he is likely to evolve before the hardware biologist; after all, he studies only one animal.

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EFFECTS OF POLLUTION ON AQUATIC LIFE

I INTRODUCTION

A The effluent from any given industrial plant may be combined with municipal sewage, and/or wastes from other industries. This may occur in the sewerage system or in a natural body of water.

1 Toxic wastes may inhibit biota of treatment plant as well as life in receiving stream.

2 Organic wastes may simply increase sewage-type load on plant and stream.

3 The above effects may be reinforced or neutralized by a complex of industrial wastes.

B The general overall character of a body of water may be subtly changed over a period of time.

II The principle of limiting factors (see Figure 1) deals with the response of organisms to various factors in the environment.

A Liebig's Law of the Minimum (Figure 1) states that the distribution of a species may be limited by one or more essential environmental factors which occur in minimal quantities.

B Shelford on the other hand pointed out in his Law of Tolerance (Figure 1) that there are also maximum values of most environmental factors which can be tolerated. In between these two extremes there are ranges which may be called "optimum" for factors useful to the organism. Purely deleterious factors on the other hand have a maximum tolerable value, but no optimum. The range between the maximum concentration (greater than zero) which kills no organism and the minimum concentration which kills all organisms is known as the "critical range."

C These principles apply to all aquatic life whether in a stream, lake, estuary, or treatment plant. They are the basis for the control or regulation of biological conditions.

III INDIRECT TOXICITY: MODIFICATIONS OF THE ENVIRONMENT WHICH AFFECT AQUATIC LIFE

A Deposition of inert precipitates and silt tends to smother bottom organisms. Contributing materials include silt or sand from erosion due to poor agricultural practices, rock flour or tailings from mining or quarry operations, mica, coal washings, sawdust and debris from lumbering, insoluble precipitates or complexes from chemical industries.

1 Vulnerable organisms include important fish foods such as insect larvae and snails; also fish eggs, bottom-living algae such as diatoms, and many others.

2 Physical injury to delicate membranes of eyes, and gills may also result.

3 Inert suspended materials and dyes reduce light penetration, suppress photosynthesis and hence biological productivity. They also prevent game fish and other predators from seeing their prey, thereby reducing the efficiency of food utilization.

The word "stream" should be interpreted in most cases to mean "river," "lake," "estuary," etc., as applicable.

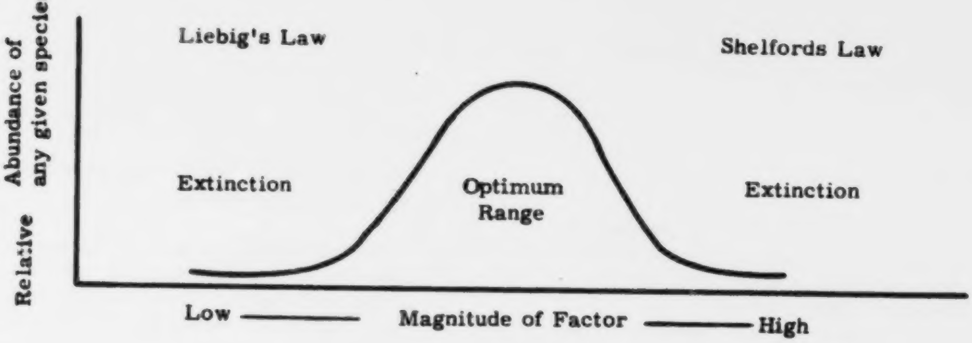

Figure 1. EFFECTS OF ENVIRONMENTAL FACTORS

B Wastes of significant heat content may change the "climate" of a body of water. Temperature may be higher or lower than normal.

1 Abnormally low summer temperatures may prevent the reproduction of some of the typical inhabitants, on the other hand colder water forms such as trout may be enabled to survive.

2 Abnormally high winter temperatures may encourage a rapid development of some species, thus for example, causing an early emergence of some insect followed by its death from normal winter temperatures. Southern forms may also invade more northerly waters, sometimes leading to a year-round nuisance from flying swarms of adults such as caddis flies.

3 Artificially produced high temperatures, often lack dependability. It is discouraging for organisms to spend six days in summer temperatures in January, only to freeze to death over the weekend because no one warned them that the plant would shut down!

4 Excessively high summer temperatures, even for a few hours once a year, probably represent the greatest temperature danger. Some species of fish can adjust to temperatures approaching 100° F, if the change takes place slowly. Each species however, has some maximum temperature above which it cannot survive (Figure 1).

a Quick temperature changes are fatal at much lower values.

b Lack of oxygen due to low solubility at high temperatures or from an increase in the rate of the BOD, also contributes greatly to high temperature mortalities.

C Oxygen-consuming wastes kill by depleting the free dissolved oxygen resources.

1 Amount present, rather than percentage of saturation, is usually more significant.

2 Minimum amounts rather than averages are most critical.

a Any species can survive something less than the optimum concentration of DO for a limited period of time. There is, however, some concentration for any given temperature, which will eventually result in the death of that species. Let us call this the "critical" DO.

b As the DO falls below the critical concentration, survival time eventually drops to zero.

c The absolute values of these thresholds vary with the species and other factors. Five mg O_2 per liter is often listed as a minimum permissible value to maintain a well-rounded healthy population of fishes on a year-round basis.

3 Low oxygen tensions may also increase the toxicity of certain chemicals.

D pH

1 "pH" is a logarithmic expression of the hydrogen ion concentration in a solution. Hydrogen ions ($H+$) in certain concentrations are toxic to aquatic life (as are also hydroxyl ions: OH^-). Aquatic life in relative abundance and variety can be found in waters ranging from approximately pH 5 to 9. Thriving communities including algae, insects, and fish have been studied in waters with a pH of at least 11.

2 Many species of aquatic organisms can adjust to pH values over a wide range. Sudden change of any kind however can be fatal.

3 Most metals and other toxic substances in dilute solution tend to become less toxic at high pH values. A notable exception is ammonia.

IV POLLUTION WHICH RENDERS FISH OR SHELLFISH UNUSABLE OR INTERFERES WITH THEIR CAPTURE

A Radioactivity at levels currently found in our waters has not been observed to adversely affect aquatic life itself. It may however, be taken up with food materials and render fish or fishery products unusable.

1 Radioactive nuclides (forms of chemicals) are taken up by the plants (predominantly algae) in the processes of photosynthesis and other types of protoplasmic synthesis. There is no selection between nuclides on the basis of radioactivity.

2 As the chemicals originally assimilated by the algae are "eaten up the food chain" (from algae to invertebrates to small fish to large fish to man and other predators) their radioactivity moves along with them.

3 Thus radioactivity is acquired by fishes essentially through food, and scarcely at all by direct assimilation or absorption.

4 Plankton-feeding organisms such as herrings, oysters, and clams acquire radioactivity directly from the algae on which they feed. Since they concentrate this food from large volumes of water, they may be much "hotter" than the surrounding water itself.

B Fish may be repelled or driven out of an area by obnoxious chemicals. This may simply result in their scarcity or absence from a given locale, or it may prevent their swimming up a river to spawn. In this case the species would soon disappear and be lost to the community.

C Color, odor, oil, floating scum, bacterial slimes, and other such materials tend to discourage sport fishing and interfere with gear used by commercial fisheries.

D Sublethal concentrations of chemicals such as phenol, benzene,oil, 2-4-D, etc., may impart an unpleasant taste to fish flesh, even when present in very dilute concentrations. This is nearly as detrimental to the fisheries as a complete kill, and of course applies to shellfish as well as fin fish.

E Minamata disease was first described from Minamata, Japan, as a disorder resulting from eating various seafoods taken from Minamata Bay, Kyushu, Japan. The disease results from industrial toxicity, in this case an organic mercury compound, transmitted to a wide variety of local marine seafood species. These organisms are not known to be affected, but acting as "transvectors," pass the toxin along to predators or human consumers. Over 30% mortality occurred in Minamata among people eating local seafood.

1 It may be important to note that a fish kill was recently reported from a TVA lake in this country resulting from mercury leaching from corroded 50 gallon drums used as floats by marinas.

2 Bird and fish kills have recently occurred in Swedish lakes resulting from mercury compounds from pulp mills. Levels in pike exceed the WHO standards for human consumption and the local population has been advised not to eat pike more than once a week! Cases of high mercury levels are increasing.

V DIRECT TOXICITY: AFFECTS THE ORGANISM ITSELF

Fish kills are often the result of direct toxicity. If this is sufficiently potent to kill at once, or within a few days, it is called acute, and is often observed as a "fish kill."

Action that may require weeks or months to be effective may be referred to as low-level, cumulative, or chronic toxicity, and is more often observed as simply a reduction of productivity: "Fishin' ain't what it used to be." Examples of chemicals often believed to be involved include: acids, alkalines, ammonia, chlorine, cyanides, metals, phenols, solvents, sulfides, synthetic organic chemicals, oil field brines, pesticides, herbicides, detergents and others.

A Acute toxicity may be so broadly effective that many forms of life are affected at one time, or it may be highly selective. It may result from a low concentration of a highly toxic material or a high concentration of a relatively less toxic material.

1 It is frequently encountered as a "slug" resulting from a dump or spill, followed by normal, relatively non-toxic conditions as the mass of water containing the poison flows on downstream, or is deflected by tidal movements.

2 Acute toxicity can be evaluated by means of the toxicity bioassay technique and various modifications (Figure 2).

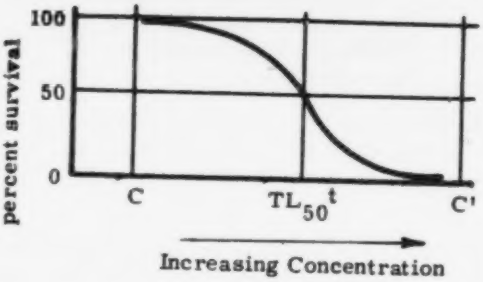

Figure 2 - Critical Range

C: maximum concentration at which no fish die, C': minimum concentration at which all die. TL_{50}^t: 50% tolerance limit (concentration tolerable to 50% of the population) for time t.

B Chronic or low-level toxicity may change the entire population balance.

1 Susceptible species of either fish or fish food organisms may die off, thereby permitting tolerant species to flourish for lack of competition.

2 If algae and/or invertebrate food organisms are killed off fish may die or move out of the area.

3 Weakened individuals are more susceptible to attack by parasites and disease, such as the aquatic fungus Saprolegnia.

4 Reproductive potential may be altered. Eggs or fry may or may not be more susceptible to toxic substances than adults.

5 Host fish for mussel (unionidae) life cycle may not survive.

6 The result may be a slow and subtle alteration of the characteristics of a stream over an extended period of time.

C The specific physiological mechanisms involved are infinite in variety and but little known. Included are such processes as enzyme inhibition as in the case with some of the pesticides, and over stimulation of mucous membranes of the gills, leading to death by suffocation.

D There are a number of excellent diagnostic techniques for the examination of dying fish, these include pathogenic bacteria, parasites, some metals, and certain pesticides. None are routine but require specific handling and preservation techniques.

E A recently developed procedure for protecting aquatic life from deleterious substances is biomonitoring. This is the continuous monitoring or surveillance of an effluent for toxicity by means of a system for exposing living organisms (such as fish or invertebrates) to a continuously flowing stream in a dilution just below the known danger point. Should the toxicity of the substance increase the test organisms respond in some recognizable manner, thus giving warning that corrective measures need to be initiated.

VI MECHANISMS OF POLLUTION TOLERANCE AND SENSITIVITY

The fact that some organisms are more resistant to pollution than others needs no emphasis. The matter of "why?" and "how?" on the other hand, is quite another question. In some cases the answer is obvious, in others not. In general we can say that the adaptations of certain species enable them to resist certain types of natural conditions such as organic deposits or sand bars. When man artificially creates conditions such as sludge banks, or sand bars, organisms which can tolerate such conditions move in, survive, and often thrive. Other forms are eliminated.

A Organic pollution is essentially non-toxic. Its typical result as noted above is oxygen depletion, physical turbidity, and smothering blankets of sediment or sludge.

B Devices and mechanisms for living in oxygen-poor or oxygen-free water include the following:

1 Obtaining oxygen from the air by means of periodic trips or access to the surface.

a The snorkel tube of the rat-tailed maggot.

b Periodic trips of the mosquito larvae and Corixidae or water boatmen. The mosquito takes air directly into its respiratory system, the water boatman into a trap or space beneath the wing covers, as well as into a layer of air held by fine hairs or "pile" all over its body.

c Behavior of the air breathing snails such as Physa which have an internal lung cavity.

d Insects which tap into air tubes in aquatic plants.

e Fishes which gulp air at surface or breathe surface water.

2 Special devices and behavior for respiration of water

a Hind intestine respiratory structures of dragonfly larvae permits respiration in silt-laden water.

b Movement of gill covers and similar structures in isopods and certain insect groups maintains a current of water over respiratory organs.

c Body movements of chironomid larvae create water current in tibe. Sludge worms and other annelids also create water movement by means of sinuous body movements.

3 Physiological and behavioral adaptations to endure low oxygen tensions.

   a Forms possessing accessory respiratory pigments such as hemoglobin might be expected to be able to be able to extract the last vestige of dissolved oxygen from the water. Two groups famous for resisting low DO do have hemoglobin: the larvae of certain Chironomid midge flies, and small annelid worms such as sludge worms. (it should be noted however, that the hemoglobin in each case is simply dissolved in the blood plasma, rather than being concentrated in special corpuscles as is the case in the more efficient vertebrate system.)

   b The mere possession of hemoglobin however, does not seem to assure tolerance of low DO (Walshe '47). Larvae of the midge *Tanytarsus spp.* have hemoglobin, but will not tolerate oxygen-poor waters. Hemoglobin-bearing *Chironomus bathopilus* is moderately tolerant, and *Chironomus plumosus* is highly tolerant, however.

   c During periods of low DO, *Chironomus plumosus* apparently respires carbohydrates as usual, but excretes excess lactic acid instead of accumulating it.

   d Various species of *Daphnia* (microcrustacea) have been shown to accumulate hemoglobin in oxygen-poor waters but not in oxygen-rich waters (Fox '47). No clear adaptive significance has yet been proven however.

C Advantageous Feeding Habits

All highly organic pollution tolerant organisms are scavengers, and hence find an abundance of food. Most are relatively defenseless and hence have normally high reproductive rate. The result in a polluted situation is thus usually an extreme abundance.

D The reverse problem is why are intolerant species intolerant?

1 A physiological requirement for higher oxygen levels is probably most basic.

2 Turbidity would hamper any organisms employing sight in any way.

3 Absence of light would suppress the growth of green algae, and hence also restrict the growth of algae feeders.

E Inert silts by themselves have many damaging effects such as abrasive or smothering action.

Biological mechanisms for enduring inert silt or sand pollution are not numerous, and consequently such locations are usually known as biological deserts. Since some life exists even in deserts however, a few forms may occasionally be found. In general they are typical sand or mud dwellers. Since the available food in such a substrate is at best of a very low order, inhabitants of these situations must either seek buried or trapped food particles or capture food from the passing waters.

1 If there is no BOD involved, and water and oxygen circulate down into the deposit, burrowing forms such as certain mayflies, annelid worms, ammocetes lamprey larvae, microcrustaceans, and others may burrow down to depths of two feet or more. Fish eggs normally deposited in gravel and newly hatched larvae are also dependent on circulating water. Such a population can be killed overnight by a layer of fine sediment or sludge which seals the surface to water circulation.

2 Water or plankton feeders include clams and mussels which can move about freely in a soft, shifting bottom, thus keeping on top of silt or sand as

it accumulates. If deposition is actively taking place, however, there will probably be so much turbidity in the water that plankton (food) organisms are unable to live. Under such circumstances certain clams and snails have the ability to close the shell so tightly by means of valves or an operculum that all contact is lost with the environment for extended periods, during which CO_2 tends to lower the rate of body metabolism. Organisms of this type have been reported to be dug up with sand and gravel and incorporated into concrete products while still alive. Emergence of a population of asiatic clams (Corbicula) for example, just as a big block of concrete is setting is said to be rough on contractors!

3 An interesting situation occasionally develops in estuaries where mud of moderate organic content is slowly deposited over oyster beds. The oysters are unable to move, but as they grow, their shells tend to bend upward above the accumulating silt, and may grow to several inches in length while growing very little in width. Crowding brings about a similar reaction in the effort to avoid being buried.

F Few generalizations can be offered relative to toxic pollution except that toxicity is relative, and all forms do not respond equally to a given toxicant.

1 Few mechanisms of toleration can be listed, beyond the natural resistance that certain forms may have for a given condition. For example, some marine species may survive a salt concentration that is toxic to freshwater species. Over a period of several generations, some species may develop a genetic resistance to some toxicant such as insecticides in the same way that DDT-resistant strains of houseflies have developed. Copper sulfate, and chlorine-resistant strains of algae such as Cosmarium for example, may develop in treated water supply reservoirs.

2 Some bottom in-fauna organisms such as annelid worms may retreat down into burrows until a slug of undesirable water passes.

3 Molluscs may close shells tightly for the same purpose. The metabolic rate is known to diminish with the increase of CO_2 inside the closed shell, thereby enabling them to remain tightly sealed for extended periods of time.

VII EFFECTS OF LIFE HISTORY STAGES

A In order to survive in a polluted area, each life history stage of an indigenous organism must be able to survive in turn.

B If some given life history stage cannot tolerate conditions, and the species is present:

1 Fortuitous changes may occur at the proper time(s) to permit survival of the more susceptible stages(s) or:

2 Recruitment from less polluted areas may occur.

C Some examples of reproductive stages or procedures which might affect pollution sensitivity:

1 Egg or egg-like stages are often enclosed in protective membranes, jelly masses, or cases. May remain dormant until favorable conditions develop.

2 Eggs may be deposited in locations where they are less exposed to polluted water as:

buried in the gravel,
on the surface film,
on rocks over the water moistened by spray,
on mud surface near water,
or in locations where maximum water circulation is encountered as at lip of waterfall.

3 Eggs may require minimal DO due to low metabolic rate.

4 Eggs deposited on or in bottom may be susceptible to smothering.

5 Newly hatched larvae often continue to live on stored yolk material for a time. On beginning to take natural food, they may be killed by toxic content thereof, such as organochlorines.

6 Some forms such as certain sludge worms commonly reproduce by (vegetative) fragmentation, hence avoiding egg and larva stages.

VIII NATURAL SELECTION AND ACCLIMATIZATION TO POLLUTION

A Known biological mechanisms for selective breeding of pollution resistant strains operate in nature among fishes as among other organisms.

1 Studies of population genetics indicate that after some finite number of generations of population stress (e.g., exposure to a given pollutant), permanent heritable resistance may be expected to develop.

2 If the environmental stress (or pollutant) is removed prior to the time that permanent resistance is developed in the population, reversion to the non-resistant condition may occur within a relatively few generations.

3 Habitats harboring populations under stress in this manner are often marked with the dead bodies of the unsuccessful individuals.

B Individual organisms on the other hand can over a period of time (less than one life cycle) develop a limited ability to tolerate different conditions, e.g., pollutants:

1 With reference to all categories of pollutants both relatively facultative and obligate species are encountered (e.g., euryhaline vs stenohaline, eurythermal vs stenothermal).

2 This temporary somatic acclimatization is not heritable.

C A given single-species collection or sample of living fishes may therefore represent one or more types of pollution resistance:

1 A sample of an original population which has been acclimated to a given stress in toto.

2 A sample of the surviving portion of an originalpopulation, which has been "selected" by the ability to endure the stress. The dead fish in a partial fish kill are that portion of the original population unable to endure the stress.

3 A sample of a sub-population of the original species in question which has in toto over a period of several generations developed a heritable stress resistance.

D Any given multi-species field collection will normally contain species illustrative of one or more of the conditions outlined above.

ACKNOWLEDGMENTS:

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THE EFFECTS OF ORGANISMS ON POLLUTION AND THE ENVIRONMENT

I INTRODUCTION

A Pollution is often studied as a factor affecting the biota, but it is equally important to recognize the environmental changes produced by the biota.

B According to Westlake, under many conditions "....the environment is almost as much a product of the community as the community is of the environment."

II SOME ENVIRONMENTAL EXAMPLES

A Diatom Blooms

"...Asterionella (an oil storage alga) produces an autotoxin (autoantibiosis) which will inhibit itself, may stimulate or inhibit other species that store oil, but always stimulate algae that store starch. For example, Asterionella may produce a bloom and inhibit itself, but stimulate a population of Synedra. These oil storage algae produce a substance that stimulates a starch-storing alga, Coelastrum, which may stimulate another starch-storing organism, Cosmarium, and they, in turn, stimulate an oil storing species of Dinobryon." Patrick.

B The altered structure of the plankton community due to the introduction of the alewife

C Fecal deposit feeders in the estuarine environment

D Particle feeders are successful in the pipe clogging community and are generally (Sebestyén):

1 Sessile

2 Suspension feeders

3 Have motile larvae

4 Resistant stages

E Biogeochemical Cycles

In terms of biomass and energy flow, the mussel Modiolus (Figure 1) is a relatively minor component of the marsh community. However, they have been demonstrated to have a major effect on the recycling and retention of valuable phosphorus; thereby maintaining fertility and production of autotrophs (Odum).

F Sudd (dense aggregations of floating weeds)

Flowering aquatic plants are a serious problem in shallow, stagnant, or slow-flowing water in many tropical countries. They are expensive liabilities in newly impounded reservoirs in developing nations.

G Biological Pollution

Contamination of living native biotas by introduction of exotic life forms has been called biological pollution by Lachner et al. Some of these introductions are compared to contamination as severe as a dangerous chemical release. They also threaten to replace known wildlife resources with species of little or unknown value.

1 Tropical areas have especially been vulnerable. Florida is referred to as "a biological cesspool of introduced life".

2 Invertebrates

a Asian Clams have a pelagic veliger larvae, thus, a variety of hydro installations are vulnerable to subsequent pipe clogging by the adult clams.

b Melanian snails are intermediate hosts for various trematodes parasitic on man.

3 Vertebrates

a At least 25 exotic species of fish have been established in North America.

b Birds, including starlings and cattle egrets.

c Mammals, including nutria.

4 Aquatic plants

Over twenty common exotic species are growing wild in the United States. The problem of waterway clogging has been especially severe in parts of the Southeast.

III In polluted environments, there is a more noticeable change in balance, time response, and effects.

A Organic Pollution

The conditions here are classic and well described. There is a succession of biological communities (Figure 2) each of which modify the environment and water properties, thus, the effects are predominately biological.

1 Tubificidae (aquatic earthworms) in the first zone may reach as many as 1,7000,000/m^2 and move up to 50 tons of mud per acre per day.

2 In the second zone chironomids (midge larvae) are found in thousands per square meter and may reduce the DO level by one and one-half ppm per stream mile.

3 The Isopod (sowbug) zone (the genus Asellus or Lirceus depending on locality) third in succession also may reach a density of thousands per square meter, a further oxygen demand due to respiration. (Figure 2)

4 The filamentous green alga Cladophora in both streams and lakes responds to organic enrichment by producing dense growths. (Figure 3)

5 Higher aquatic plants such as Potamogeton pectinatus may also be involved in these ecological changes in streams, particularly respiration vs. photosynthesis. There is correlation between weed bed growths, velocity and silt deposition. In some streams these massive growths on sloughing off foul water intakes and reduce DO levels as they decompose.

6 Sphaerotilus and/or slime growths below organic wastes, by metabolic demands while living and decomposition after death, impose a high BOD load on the stream and can severely deplete the dissolved oxygen. (Figure 3)

7 Blackflies (Diptera, family Simuliidae) often reach large populations below organic waste sources, filter feed on this material and in so doing, further degrade stream conditions with their fecal deposits.

B Inorganic and Toxic Pollution

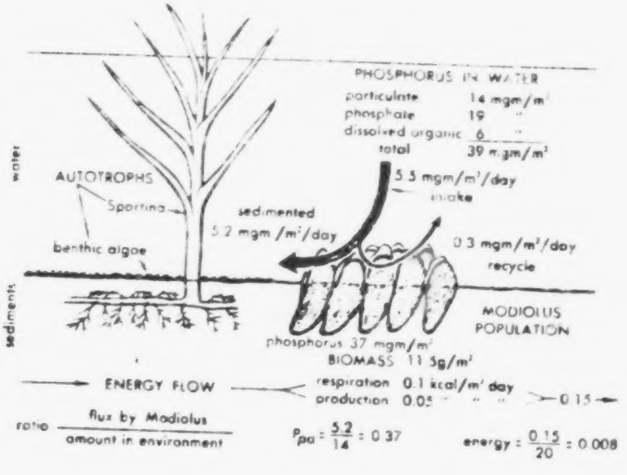
When progressive changes occur they are rarely produced by the biological community.

C Biological Magnification

Biological magnification is an additional chronic effect of toxic and other pollutants (such as heavy metals, pesticides, carcinogens, teratogens, radionuclides, bacteria, and viruses) which must be recognized and examined before clearance can be given for the disposal of a waste product into natural waters. To paraphrase Odum we could give nature an apparently innocuous amount of pollutant and have her give it back to us in a lethal or detrimental package.

1 Many animals, and especially bivalves, have the ability to remove from the environment and store in their tissues substances present at nontoxic levels in the surrounding water.

a This process may continue in the clam or fish, for example, until the body burden of the toxicant reaches such levels that the animal's death would result if the pollutant were released into the bloodstream by physiological activity.


water
sediments
AUTOTROPHS
Spartina
benthic algae
PHOSPHORUS IN WATER
particulate 14 mgm/m²
phosphate 19 "
dissolved organic 6 "
total 39 mgm/m²
5.5 mgm/m²/day
intake
sedimented
5.2 mgm/m²/day
0.3 mgm/m²/day
recycle
MODIOLUS
POPULATION
phosphorus 37 mgm/m²
BIOMASS 11.5g/m²
ENERGY FLOW
respiration 0.1 kcal/m² day
production 0.05 " "
0.15
ratio flux by Modiolus / amount in environment
Ppa = 5.2/14 = 0.37
energy = 0.15/20 = 0.008

(Reproduced from Figure 4-4, from Ecology by Eugene P. Odum, copyright (c) 1963 by Holt, Rinehart and Winston, Inc. used by permission of Holt, Rinehart and Winston, Inc.)

Figure 1. The role of a shellfish (mussel) population in the cycling and retention of phosphorus in an estuarine ecosystem.

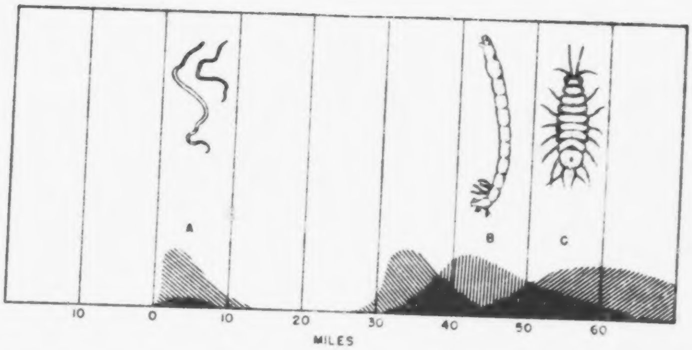


Figure 2. Linear alterations in populations of Tubificids (A) Chironomids (B), and Isopods (C) (from Bartsch). Zone C is often referred to as the Cladophora-Asellus Zone.

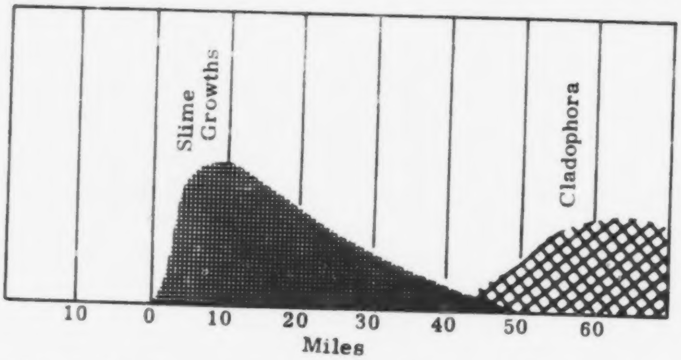


Figure 3. Linear alterations in populations of slime growths and Cladophora (modified from Bartsch)

b This may occur, as in the case of chlorinated hydrocarbon pesticides (such as DDT and endrin) stored in fat depots, when the animals food supply is restricted and the body fat is mobilized.

c The appearance of the toxicant in the bloodstream causes the death of the animal.

2 The biological magnification and storage of toxic residues of polluting substances and microorganisms may have another serious after effect.

a Herbivorous and carnivorous fish at lower trophic stages may gradually build up DDT residues of 15 to 20 mg/l without apparent ill effect.

b Carnivorous fish, mammals, and birds preying on these contaminated fish may be killed immediately or suffer irreparable damage because of the pesticide residue or infectious agent.

c Commercial shellfisheries are damaged by toxins produced by some dino-flagellate blooms in nearshore waters.

IV In summary, the biological causes of DO changes, associated changes in pH and CO_2, ammonia, nitrates, and sulphides, require study if the effects of organic pollution are to be calculated and predicted. Further biological effects on pollution include the relation to fouling organisms; stabilization of sediments in estuaries; recycling of nutrients; and problems of biological magnification.

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GLOBAL DETERIORATION AND OUR ENVIRONMENTAL CRISIS

I FROM LOCAL TO REGIONAL TO GLOBAL PROBLEMS

A Environmental problems do not stop at national frontiers, or ideological barriers. Pollution in the atmosphere and oceans taints all nations, even those benignly favored by geography, climate, or natural resources.

1 The smokestacks of one country can pollute the air and water of another.

2 Toxic effluents poured into an international river can kill fish in a neighboring nation and ultimately pollute international seas.

B In Antarctica, thousands of miles from pollution sources, penguins and fish contain DDT in their fat. Recent layers of snow and ice on the white continent contain measurable amounts of lead. The increase can be correlated with the earliest days of lead smelting and combustion of leaded gasolines.

C International cooperation, therefore, is necessary on many environmental fronts.

1 Sudden accidents that chaotically damage the environment - such as oil spills from a tanker at sea - require international cooperation both for prevention and for cleanup.

2 Environmental effects cannot be effectively treated by unilateral action.

3 The ocean can no longer be considered a dump.

D "One of the penalties of an ecological education is that one lives alone in a world of wounds. Much of the damage inflicted on land is quite invisible to laymen. An ecologist must either harden his shell and make believe that the consequences of science are none of his business, or he must be the doctor who sees the marks of death in a community that believes itself well and does not want to be told otherwise." Aldo Leopold

II CHANGES IN ECOSYSTEMS ARE OCCURRING CONTINUOUSLY

A Myriad interactions take place at every moment of the day as plants and animals respond to variations in their surroundings and to each other. Evolution has produced for each species, including man, a genetic composition that limits how far that species can go in adjusting to sudden changes in its surroundings. But within these limits the several thousand species in an ecosystem, or for that matter, the millions in the biosphere, continuously adjust to outside stimuli. Since interactions are so numerous, they form long chains of reactions.

B Small changes in one part of an ecosystem are likely to be felt and compensated for eventually throughout the system. Dramatic examples of change can be seen where man has altered the course of nature. It is vividly evident in his well-intentioned but poorly thought out tampering with river, lake, and other ecosystems.

1 The Aswan High Dam

2 The St. Lawrence Seaway

3 Lake Kariba

4 The Great Lakes

5 Valley of Mexico

6 California earthquake (Scientific American 3981, p. 333)

7 Everglades and the Miami, Florida Jetport

8 Copperhill, Tennessee (Copper Basin)

9 (You may add others)

C Ecosystem Stability

1 The stability of a particular ecosystem depends on its diversity. The more interdependencies in an ecosystem, the greater the chances that it will be able to compensate for changes imposed upon it.

2 A cornfield or lawn has little natural stability. If they are not constantly and carefully cultivated, they will not remain cornfields or lawns but will soon be overgrown with a wide variety of hardier plants constituting a more stable ecosystem.

3 The chemical elements that make up living systems also depend on complex, diverse sources to prevent cyclic shortages or oversupply.

4 Similar diversity is essential for the continued functioning of the cycle by which atmospheric nitrogen is made available to allow life to exist. This cycle depends on a wide variety of organisms, including soil bacteria and fungi, which are often destroyed by pesticides in the soil.

D Biological Pollution

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1 Tropical areas have especially been vulnerable. Florida is referred to as "a biological cesspool of introduced life".

2 Invertebrates

a Asian Clams have a pelagic veliger larvae, thus, a variety of hydro installations are vulnerable to subsequent pipe clogging by the adult clams.

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b Birds, including starlings and cattle egrets.

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Over twenty common exotic species are growing wild in the United States. The problem of waterway clogging has been especially severe in parts of the Southeast.

5 Pathogens and Pests

Introduction of insect pests and tree pathogens have had severe economic effects.

III LAWS OF ECOLOGY

A Four principles have been enunciated by Dr. Barry Commoner.

1 Everything is connected to everything else.

2 Everything must go somewhere.

3 Nature knows best.

4 There is no such thing as a free lunch.

B These may be summarized by the principle, "you can't do just one thing."

IV THE THREE PRINCIPLES OF ENVIRONMENTAL CONTROL (Wolman)

A You can't escape.

B You have to organize.

C You have to pay.

V POLLUTION COMES IN MANY PACKAGES

A The sources of air, water, and land pollution are interrelated and often interchangeable.

1 A single source may pollute the air with smoke and chemicals, the land with solid wastes, and a river or lake with chemical and other wastes.

2 Control of air pollution may produce more solid wastes, which then pollute the land or water.

3 Control of wastewater effluent may convert it into solid wastes, which must be disposed of on land, or by combustion to the air.

4 Some pollutants - chemicals, radiation, pesticides - appear in all media.

B "Disposal" is as important and as costly as purification.

VI PERSISTENT CHEMICALS IN THE ENVIRONMENT

Increasingly complex manufacturing processes, coupled with rising industrialization, create greater amounts of exotic wastes potentially toxic to humans and aquatic life.

They may also be teratogenic (toxicants responsible for changes in the embryo with resulting birth defects, ex., thalidomide), mutagenic (insults which produce mutations, ex., radiation), or carcinogenic (insults which induce cancer, ex., benzopyrenes) in effect.

A Metals - current levels of cadmium, lead, and other substances whose effects on humans and fish and wildlife are not fully understood constitute a mounting concern. Mercury pollution, for example, has become a serious national problem, yet mercury has been present on earth since time immemorial. More research is needed, yet we dare not relax our standards until definitive answers have been provided.

B Pesticides

1 A pesticide and its metabolites may move through an ecosystem in many ways. Hard (pesticides which are persistent, having a long half-life in the environment includes the organochlorines, ex., DDT) pesticides ingested or otherwise borne by the target species will stay in the environment, possibly to be recycled or concentrated further through the natural action of food chains if the species is eaten. Most of the volume of pesticides do not reach their target at all.

2 Biological magnification

Initially, low levels of persistent pesticides in air, soil, and water may be concentrated at every step up the food chain. Minute aquatic organisms and scavengers, which screen water and bottom mud having pesticide levels of a few parts per billion, can accumulate levels measured in parts per million - a thousandfold increase. The sediments including fecal deposits are continuously recycled by the bottom animals.

a Oysters, for instance, will concentrate DDT 70, 000 times higher in their tissues than it's concentration in surrounding water. They can also partially cleanse themselves in water free of DDT.

b Fish feeding on lower organisms build up concentrations in their visceral fat which may reach several thousand parts per million and levels in their edible flesh of hundreds of parts per million.

c Larger animals, such as fish-eating gulls and other birds, can further concentrate the chemicals. A survey on organochlorine residues in aquatic birds in the Canadian prairie provinces showed that California and ring-billed gulls were among the most contaminated. Since gulls breed in colonies, breeding population changes can be detected and related to levels of chemical contamination. Ecological research on colonial birds to monitor the effects of chemical pollution on the environment is useful.

C "Polychlorinated biphenyls" (PCB's). PCB's are used in plasticizers, asphalt, ink, paper, and a host of other products. Action has been taken to curtail their release to the environment, since their effects are similar to hard pesticides.

D Other compounds which are toxic and accumulate in the ecosystem:

1 Phalate esters - may interfere with pesticide analyses

2 Benzophyrenes

3

VII EXAMPLES OF SOME EARLY WARNING SIGNALS THAT HAVE BEEN DETECTED BUT FORGOTTEN, OR IGNORED.

A Magnetic micro-spherules in lake sediments now used to detect changes in industrialization indicate our slowness to recognize indicators of environmental change.

B Salmonid fish kills in poorly buffered clean lakes in Sweden. Over the past years there had been a successive increase of SO_2 in the air and precipitation. Thus, air-borne contamination from industrialized European countries had a great influence on previously unpolluted waters and their life.

C Minimata, Japan and mercury pollution.

D Organochlorine levels in commercial and sport fishing stocks, ex., the lower Mississippi River fish kills.

E You may complete the following:

1

2

VIII SUMMARY

A Ecosystems of the world are linked together through biogeochemical cycles which are determined by patterns of transfer and concentrations of substances in the biosphere and surface rocks.

B Organisms determine or strongly influence chemical and physical characteristics of the atmosphere, soil, and waters.

C The inability of man to adequately predict or control his effects on the environment is indicated by his lack of knowledge concerning the net effect of atmospheric pollution on the earth's climate.

D Serious potential hazards for man which are all globally dispersed, are radionuclides, organic chemicals, pesticides, and combustion products.

E Environmental destruction is in lock-step with our population growth.

ACKNOWLEDGEMENT:

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FUNDAMENTALS OF THE TOXICITY BIOASSAY

I INTRODUCTION

A The toxicity bioassay procedure herein discussed is intended for use by industrial and other laboratories.

B Its objective is to evaluate the toxicity of wastes and other water pollutants to fish or other aquatic organisms.

C This basic procedure evaluates relatively acute toxicity only (chronic or cumulative toxicity requires more extensive study).

D Potential applications are numerous.

1 Dilution and/or treatment necessary to avoid acute toxic effects can be estimated.

2 The efficacy of a treatment can be tested.

3 The potential usefulness of a proposed treatment can be estimated.

E The toxicity bioassay technique does not involve a chemical knowledge of the toxicant.

1 Synergism, antagonism, and other interactions of chemical components cannot always be anticipated, but are automatically included in the overall evaluation.

2 All chemical and physical information available is essential to the adequate interpretation and application of test results.

F The test is designed for local application. Generalizations should be made with great caution.

G Field observations should be made of results of application over a significant period of time.

H Careful distinction should be made between fish mortality due to a physiological toxicant, and that due to lack of DO.

I A uniform testing procedure is essential to effective action in water pollution control.

II ROUTINE PROCEDURE

A Test animals should be fish or other organisms of local significance.

1 Extremely resistant or extremely sensitive species should not be selected.

2 They should be species which are amenable to captivity.

3 They should be accurately identified.

4 They should be relatively uniform in size. Individuals less than 3 inches in length are usually most convenient.

5 They should be healthy and thoroughly acclimated to the laboratory.

B Test water should preferably be taken from the receiving stream just above the discharge being evaluated.

1 If this is unsuitable, cleaner waters from an upstream station may be substituted.

2 Artificial "standard" waters are not recommended for general use.

C Other Experimental Conditions

1 Temperature

The tests should be performed at a uniform temperature in the upper part of the expected summer range, e.g., 20° - 25° C for warm water fish, and 12° - 18° C for cold water species. It has been found however, that for most routine operations, ambient laboratory temperatures are satisfactory. Standard modern air conditioning, particularly if it is maintained 24 hours a day, is quite adequate.

2 Test containers should be of glass. Wide mouthed "pickle jugs" or battery jars are satisfactory. Five and one gallon sizes are both useful, but the larger size is required for conclusive results.

3 Artificial Aeration should not be used to maintain the dissolved oxygen concentration. If this falls below approximately 4 or 5 ppm at any time during the test, fewer fish should be used per container or an auxiliary oxygenation procedure invoked that is designed to void undue loss of volatile toxicants.

4 The number of test animals should not be less than 10 per concentration for reliable conclusions; these may be distributed between two or more containers.

5 Ratio of fish to solution

There should be less than 2 grams of fish per liter of test solution, preferably not more than one.

D Experimental Procedure

1 All dilutions for a given run should be prepared from the same sample.

2 Control tests are essential.

3 Duration

Tests should be run for at least 48 hours, preferably 96.

4 Dead fish should be removed as soon as observed. Survivors should be counted and recorded each 24 hours.

5 Feeding during the test should be avoided.

6 Experimental concentrations

Any appropriate concentrations may be used. A logarithmic series such as is suggested in Table I is very convenient. Concentrations can be expressed in percent by volume, parts per million by weight, or other appropriate units.

7 Expression of results

The measure of relative toxicity is the median tolerance limit (symbol: TL_m, this is the analogue of the LD_{50} of the toxicologist).

a This is the concentration which just 50% of the test animals can survive for a stipulated period of time (sometimes written TL^t_m where t = 24, 48, 96 hours, etc.)

b The TL^t_m may conveniently be estimated graphically, by plotting the experimental data on semi-logarithmic graph paper, with the test concentration laid off on the log. scale, and the percent survival on the arithmetic scale. Connect with a straight line the two successive data points representing survival values of greater than and less than 50%. Note the concentration which corresponds to 50% survival on this graph. This is the "TL^t_m". Other methods are acceptable.

III REPORTING, INTERPRETATION AND APPLICATION

A Reports should include an orderly tabulation of all pertinent data such as:

1 Identity of experimental animals

2 Their source, average size and condition, and number used per concentration

3 Source and chemical and physical analysis of experimental water

4 Experimental temperature

5 Volumes of experimental liquid in each container

6 Records of running analyses such as DO and pH

7 TL_m and data from which it was determined

B Interpretation and application will be discussed more thoroughly later. Briefly:

1 The TL_m is an estimate of the midpoint of the critical concentration range (the interval between the highest concentration at which all test animals survive, and the lowest at which they all die).

2 The problem is to extrapolate from this well established mid concentration to a safe concentration well below the "critical concentration range".

3 Initiation of regulatory procedures based on the TL_m should be followed by periodic field observations. If aquatic life flourishes, there is no problem indicated. If not, the material must be still further diluted.

IV SPECIAL PROBLEMS

A Unaerated aquaria with finite quantities of toxicant are not always satisfactory (Static Tests).

1 The toxicant may be volatile.

2 Toxic materials may be masked by a high BOD.

3 The toxicant may be progressively adsorbed or otherwise changed.

TABLE I
A Guide to the Selection of Experimental Concentrations, Based on Progressive Bisection of Intervals on a Logarithmic Scale.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5
10.0	----	----	----	----
----	----	----	----	8.7
----	----	----	7.5	----
----	----	----	----	6.5
----	----	5.6	----	----
----	----	----	----	4.9
----	----	----	4.2	----
----	----	----	----	3.7
----	3.2	----	----	----
----	----	----	----	2.8
----	----	----	2.4	----
----	----	----	----	2.1
----	----	1.8	----	----
----	----	----	----	1.55
----	----	----	1.35	----
----	----	----	----	1.15
1.0	----	----	----	----

B Standards or requirements other than those involving toxicity per se may be involved.

C Preliminary and Concurrent Investigations

  1 Obtain all available information about unknown to be tested.

  2 Does the material lend itself to this type of test?

  3 Run feasible on the spot analyses including DO.

  4 Significant quantities of solutions removed from test containers for analysis should be replaced with similar volume of same dilution.

D Wastes with a high BOD or COD

  1 Suggested preliminary tests

    a Set up two identical exploratory tests.

    b Aerate one but not the other.

    c If great difference develops between them, special procedures are indicated.

  2 Oxygenation or aeration of dilution water before making dilutions may help.

  3 Oxygenation of experimental containers during run. Pure oxygen is suggested instead of air in order to avoid the bubbling any more gas through the containers than is necessary as some of the toxic fraction may be volatile materials which would be stripped out.

    a Lead oxygen into tank through glass tube instead of breaker stone in order to keep bubbles large.

    b Control rate of bubbling. Keep it at the minimum number of bubbles per minute which will maintain 4 to 5 milligrams of oxygen per liter. Do not attempt saturation.

    c Other systems of oxygenation are available.

  4 Renewal of solutions at stated intervals (12, 24, or 48 hours) is approved. Fish are not harmed by being carefully transferred from one container to another. It is useful where:

    a Initial DO is adequate but slowly exhausted.

    b Toxicant is volatile, progressively adsorbed, precipitated, or otherwise changed.

E Continuous flow apparatus is highly desirable but expensive.

  1 Equipment more involved and subject to failure during a run.

  2 May be adapted to monitoring by use of proportioning equipment. Makes longer runs possible.

F Other Considerations

  1 Radioactive wastes must be evaluated in regard to their chemical toxicity as well as their radioactivity.

  2 Sub acute levels of many toxicants such as lead, arsenic, chromium, etc., may exert a low level chronic toxicity over a long period of time.

  3 "Safe levels" of a waste in regard to toxicity may still exceed standards of other types such as color, organic content, suspended solids, etc.

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BIOLOGICAL FIELD METHODS

I INTRODUCTION

A Due to the nature of ecological interrelationships, methods for the collection of different types of aquatic organisms differ. In general we can recognize those that swim or float and those that crawl, those that are big and those that are little. Each comprises a part of "the life" at any given survey station and consequently a "complete" collection would include all types.

B Field methods in the following outline are grouped under four general categories, the collection of:

1 Benthos (or bottom dwelling organisms). These may be attached, crawling, or burrowing forms.

2 Plankton (plancton). These are all of the microscopic plants and animals normally swimming or suspended in the open water.

3 Periphyton or "aufwuchs". This is the community of organisms associated with the surfaces of objects. Some are attached, some crawl. The group is intermediate between the benthos and the plankton.

4 Nekton. Nekton are the larger, free swimming active animals such as shrimp or fishes.

C Aquatic mammals and birds, in most cases, require still other approaches and are not included.

D There is little basic difference between biological methods for oceanic, estuarine, or freshwater situations except those dictated by the physical nature of the environments and the relative sizes of the organisms. Fish, benthos, and plankton collection is essentially the same whether conducted in Lake Michigan, Jones' Beach, or the Sargasso Sea.

1 Marine organisms range to larger sizes, and the corrosive nature of seawater dictates special care in the design and maintenance of marine equipment. Site selection and collection schedules are influenced by such factors as tidal currents and periodicity, and salinity distribution, rather than (river) currents, riffles, and pools.

2 Freshwater organisms are in general smaller, and the water is seldom chemically corrosive on equipment. Site selection in streams involves riffles, falls, pools, etc., and a unidirectional flow pattern. Lake collection may involve less predictable stratification or flow patterns.

E Definite objectives should be established in advance as to the size range of organisms to be collected and counted, i.e.: microscopic only, microscopic and macroscopic, those retained by "30 mesh" screens, invertebrates and/ or vertebrates, etc.

II STANDARD PROCEDURES

A Certain standard supplementary procedures are a part of all field techniques. In order to be interpreted and used, every collection must be associated with a record of environmental conditions at the time of collection.

1 Data recorded should include the following as far as practicable.

Location (name of river, lake, etc.)

Station number (particular location of which a full description should be on record)

Date and hour

Air temperature

Water temperature (at various depths, if applicable)

Salinity (at various depths, if applicable)

Tidal flow (ebb or flood)

Turbidity (or light penetration, etc.)

Weather

Wind direction and velocity

Sky or cloud cover

Water color

Depth

Type of bottom

Type of collecting device and accessories

Method of collecting

Type of sample (quantitative or qualitative)

Number of samples at each station

Chemical and physical data, e.g., dissolved oxygen, nutrients, pH, etc.

Collector's name

Miscellaneous observations (often very important)

2 All collecting containers should be identified at least with location, station number, sample number, and date. Spares are very handy.

3 Much transcription of data can be eliminated by using sheets or cards with a uniform arrangement for including the above data. The same field data sheet may include field or laboratory analysis.

B Compact kits of field collecting equipment and materials greatly increase collecting efficiency, especially if collection site is remote from transportation.

III PERSONAL OBSERVATION AND PHOTOGRAPHY

A Direct or indirect observation of underwater conditions has become relatively efficient.

1 Diving spheres, pioneered by William Beebe, Cousteau, Honot, Willm, and Manad are proving very important for deep water observations.

2 Use of the aqualung permits direct personal study down to over 200 feet.

3 Underwater television (introduced by the British Admiralty for military purposes) is now generally available for biological and other observations.

4 Underwater photography is improving in quality and facility.

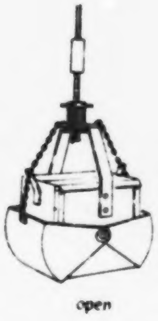
5 Underwater swimming or use of SCUBA is quite valuable for direct observation and collecting.

IV COLLECTION OF BOTTOM OR BENTHIC ORGANISMS

A Shoreline or Wading Depth Collecting Plates I, II

1 Hand picking of small forms attached to or crawling on rocks, sticks, etc. when lifted out of the

BOTTOM GRABS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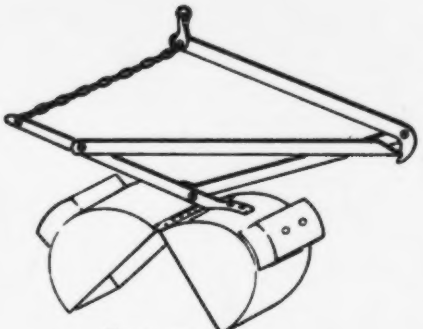
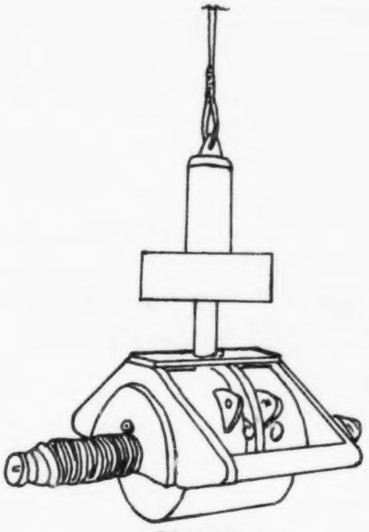
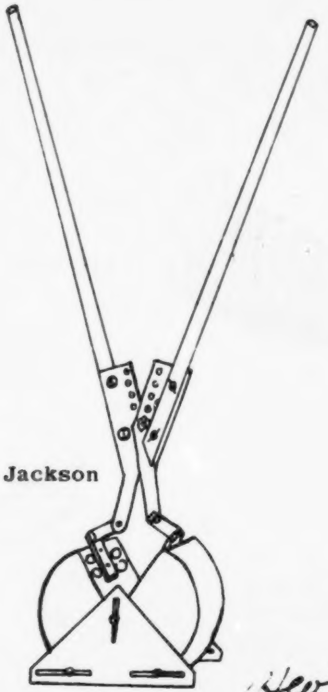
Ekman



Petersen



Shipek



Jackson

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PLATE I

LIMNOLOGICAL EQUIPMENT

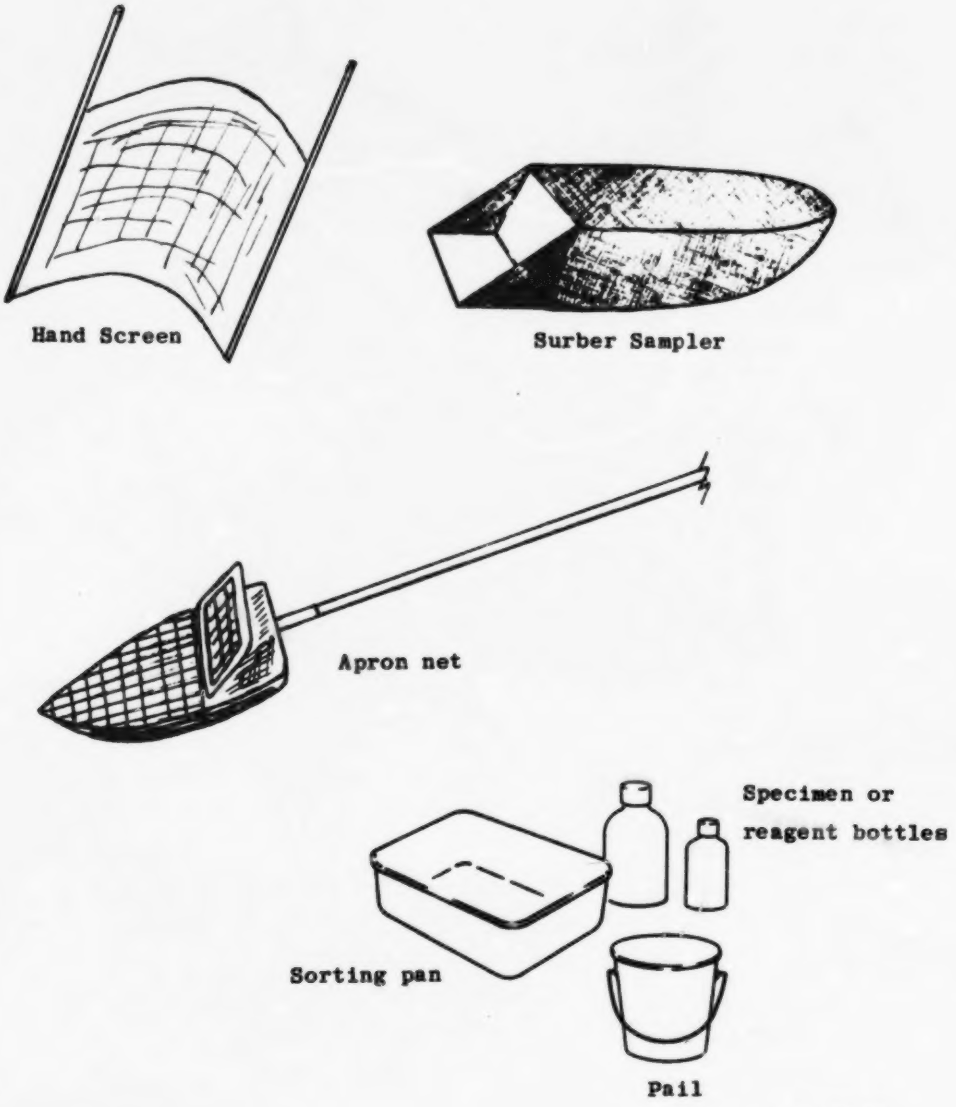

Hand Screen
Surber Sampler
Apron net
Specimen or
reagent bottles
Sorting pan
Pail

PLATE II

water is a fundamental and much used method for quickly assaying what is present and what may be expected on further search.

2 Patches of seaweed and eelgrass and shallow weedy margins anywhere are usually studied on a qualitative basis only.

  a The apron net is one of the best tools for animals in weed beds or other heavy vegetation. It is essentially a pointed wire sieve on a long handle with coarse screening over the top to keep out leaves and sticks.

  b Grapple hooks or a rake may be used to pull masses of vegetation out on the bank where the fauna may be examined and collected as they crawl out.

  c Quantitative estimates of both plants and animals can be made with a "stove pipe" sampler which is forced down through a weed mass in shallow water and embedded in the bottom. Entire contents can then be bailed out into a sieve and sorted.

  d A frame of known dimensions may be placed over an area to be sampled and the material within cropped out. This is especially good for larger plants and large bivalves. This method yields quantitative data.

3 Sand and mud flats in estuaries and shallow lakes may be sampled quantitatively by marking off a desired area and either digging away surrounding material or excavating the desired material to a measured depth. Handle-operated samplers recently developed by Jackson and Larrimore, make for more effective sampling of a variety of bottoms down to the depth of the handles. Such samples are then washed through graded screens to retrieve the organisms.

4 Ekman grabs are most useful on soft bottoms. This is a completely closing clamshell type grab with spring operated jaws. Size of grab is usually 6" × 6" or 9" × 9", the 12" × 12" size is impractical due to its heavy weight when filled with bottom material.

For use in shallow water, it is convenient to rig an Ekman with a handle and a hand operated jaw-release mechanism.

5 The Petersen type grab (described below) without weights will take satisfactory samples in firm muds, but tends to bury itself in very soft bottoms. It is seldom used in shallow water except as noted below.

B. Collecting in Freshwater Riffles or Rapids

1 The riffle is one of the most satisfactory habitats for comparing stream conditions at different points.

2 The hand screen is the simplest and easiest device to use in this situation. Resulting collections are qualitative only.

  a In use the screen is firmly planted in the stream bed. Upstream bottom is thoroughly disturbed with the feet, or worked over by hand by another person. Organisms dislodged are carried down into the screen.

  b Screen is then lifted and dumped into sorting tray or collecting jar.

3 The well-known square foot Surber sampler is one of the best quantitative collecting devices for riffles.

a It consists of a frame one foot square with a conical net attached. It is usable only in moving water.

b In use it is firmly planted on the bottom. The bottom stones and gravel within the square frame are then carefully gone over by hand to ensure that all organisms have been dislodged and carried by the current into the net. A stiff vegetable brush is often useful in this regard.

c From three to five square-foot samples should be taken at each station to insure that a reasonable percentage of the species present will be represented.

4 The Petersen type grab may be used in deep swift riffles or where the Surber is unsuitable.

a It is planted by hand on the bottom, and worked down into the bottom with the feet.

b It is then closed and lifted by pulling on the rope in the usual manner.

5 A strong medium weight dipnet is the closest approach to a universal collecting tool.

a Sweeping Weed beds and Stream Margins

This is used with a sweeping motion, through weeds, over the bottoms or in open water. A triangular shape is preferred by some.

b Stop net or Kicking Technique

This may be used as a roughly quantitative device in riffles by holding the end flat against the bottom and backing slowly up-stream disturbing the substrate with one's feet. A standard period of time is used.

c The handle should be from 4 to 6 feet long, and about the weight of a garden rake handle.

d The ring should be made of steel or spring brass, and securely fastened to the handle. It should be strong but not cumbersome; size of ring stock will depend on diameter of ring.

e The bag or net should be the strongest available, not over 1/8 inch mesh, preferably about 1/16 inch. Avoid 30 or more meshes to the inch; this is so fine that the net plugs too easily and is slow and heavy to handle.

f There should be a wide canvas apron sewed around the rim and protecting the bag. The rim may be protected with leather if desired.

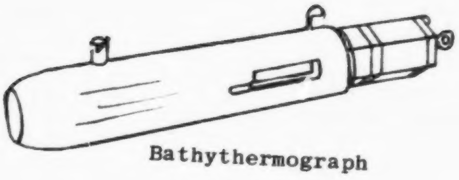
D Deep Water Benthic Collecting Plate III

1 When sampling from vessels, a crane and winch, either hand or power operated, is used. The general ideas described for shallow waters apply also to deeper waters, when practicable.

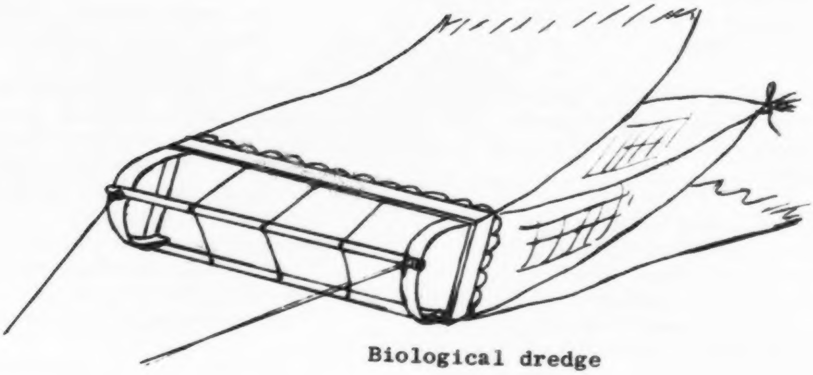
2 The Petersen type grab, seems to be the best all around sampler for the greatest variety of bottoms at all depths, from shoreline down to over 10,000 meters. (Plate I)

a It consists of two heavily constructed half cylinders closed together by a strong lever action.

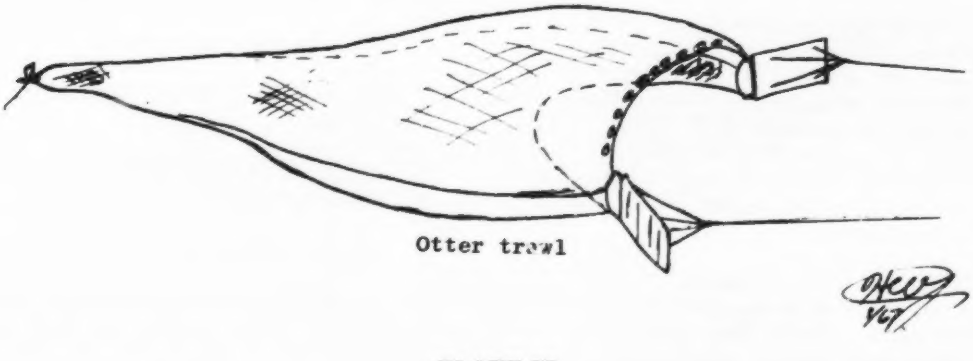
DEEP WATER EQUIPMENT



Bathythermograph



Biological dredge



Otter trawl

PLATE III

b To enable them to bite into hard bottoms, or to be used in strong currents, weights may be attached to bring the total weight up to between 50 and 100 lbs.

c Areas sampled range from 1/5th to 1/20th square meters (1/10 square meter equals approximately 1.1 square ft.)

d A Petersen grab to be hauled by hand should be fitted with 5/8 or 3/4 inch diameter twisted rope in order to provide adequate hand grip. It is best handled by means of wire ropes and a winch.

3 Other bottom samplers include the VanVeen, Lee, Holme, Smith-McIntyre, Knudsen, Ponar, and others.

4 A spring loaded sampler has recently been developed by Shipek for use on all types of bottoms. It takes a half-cylinder sample, 1/25th square meters in area and approximately 4 inches deep at the center. The device is automatically triggered on contact with the bottom, and the sample is completely protected enroute to the surface. (Plate I)

5 Drag dredges or scrapes are often used in marine waters and deeper lakes and streams, and comprise the basic equipment of several types of commercial fisheries. Some types have been developed for shallow streams. In general however, they have been little used in fresh water.

6 The above is only a partial listing of the many sampling devices available. Others that are often encountered are the orange-peel bucket, plow dredge, scallop type dredge, hydraulic dredges, and various coring devices. Each has its own advantages and disadvantages and it is up to the worker and his operation to decide what is best for his particular needs. The Petersen type and Ekman grabs are perhaps the most commonly used.

7 Traps of many types are used for various benthic organisms, especially crabs and lobsters. Artificial substrates (below) are in essence a type of trap.

8 Since most biological communities are not evenly distributed, it is advisable to routinely take at least two and preferably more samples from any one station.

E Artificial substrates rely on the ecological predilection of organisms to grow wherever they find a suitable habitat. When a small portion of artificial habitat is provided, it tends to become populated by all available species partial to that type of situation. The collector can then at will remove the habitat or trap to his laboratory and study the population at leisure.

This versatile research technique is much used for both routine monitoring and exploratory studies of pollution. It is also exploited commercially, especially for shellfish production. Types of materials used include:

1 Cement plates and panels.

2 Wood (especially for burrowing forms).

3 Glass slides (ex: Catherwood diatometer).

4 Multiple plate trap (masonite).

5 Baskets (or other containers) holding natural bottom material and either imbedded in the bottom, or suspended in the overlying water.

6 Unadorned ropes suspended in the water, or sticks thrust into the bottom.

F Sorting and Preservation of Collections

1 Benthic collections usually consist of a great mass of mud and other debris among which the organisms are hidden. Various procedures may be followed to separate the organisms.

a The organisms may be picked out on the spot by hand or the entire mess taken into the laboratory where it can be examined more efficiently (especially in rough weather). Roughly equivalent time will probably be required in either case.

b Specimens may be simply observed and recorded or they may be preserved as a permanent record.

c Organisms may be simply counted, weighed, or measured volumetrically; or they may be separated and recorded in groups or species.

2 If separation is in the field, this is usually done by hand picking, screening, or some type of flotation process.

a Hand picking is best done on a white enameled tray using light touch limnological forceps.

b Screening is one of the most practical methods to separate organisms from debris in the field. Some prefer to use a single fine screen, others prefer a series of 2 or 3 screens of graded sizes. The collection may be dumped directly on the screen and the mud and debris washed through, or it may be dumped into a bucket or small tub. Water is then added, the mixture is well stirred, and the supernatant poured through the screen. The residue is then examined for heavy forms that will not float up.

c A variation of this method in situations where there is no mud is to pour a strong sugar or salt solution over the collection in the bucket, stir it well, and again pour the supernatant through the screen. This time, however, saving the flotation solution for re-use. The heavier-than-water solution accentuates the separation of organisms from the debris (except for the heavy shelled molluscs, etc.). A solution of 2-1/2 lbs. of sugar per gallon of water is considered to be optimum.

3 Preservation or stabilization is usually necessary in the field.

a 95% ethanol (ethyl alcohol) is highly satisfactory. A final strength of 70% is necessary for prolonged storage. If the collection is drained of water and flooded with 95% ethanol in the field, a laboratory flotation separation can usually be made later, thus saving much time. Considerable quantities of ethanol are required for this procedure.

b Formaldehyde is more widely available and is effective in concentrations of 3 - 10% of the commercial formulation. However, it shrinks and hardens specimens, collector, and laboratory analyst without favor! In order to minimize bad effects from formalin, neutralized formalin is recommended. Mollusc shells will eventually disintegrate in acid formalin

c Properly preserved benthos samples may be retained indefinitely, thereby enhancing their utility.

d Refrigeration or icing is very helpful.

V MICROFAUNA AND PERIPHYTON (OR AUFWUCHS) SAMPLING

A This is a relatively new area which promises to be of great importance. The microfauna of mud and sand bottoms may be studied to some extent from collections made with the various devices mentioned above. In most cases however, there is considerable loss of the smaller forms.

B Most special microfauna samplers for soft bottoms are essentially modified core samplers in which an effort is made to bring up an undisturbed portion of the bottom along with the immediately overlying water. The best type currently seems to be the Enequist sampler which weighs some 35 kg. and takes a 100 sq. cm sample 50 cm. deep.

C Microfauna from the surface of hard sand or gravel bottoms may be sampled by the Hunt vacuum sampler. This has a bell-shaped "sampling" tube sealed by glass diaphragm. On contact with the bottom, the glass is automatically broken and the nearly bottom material is swept up into a trap.

D Periphyton attached to or associated with hard surfaces such as rock or wood may be sampled by scraping or otherwise removing all surface material from a measured area. The periphyton, however, is more effectively quantitatively sampled by artificial substrate techniques described above.

VI THE COLLECTION, OR SAMPLING OF PLANKTON PLATE IV

A Phytoplankton: A Planned Program is Desirable

1 A planned program of plankton analysis should involve periodic sampling at weekly or even more frequent intervals.

2 A well-planned study or analysis of the growth pattern of plankton in one year will provide a basis for predicting conditions the following year since seasonal growth patterns tend to repeat themselves from year to year.

a Since the seasons and the years differ, records accumulated over the years become more useful.

b As the time for an anticipated bloom of some troublesome species approaches, the frequency of analyses may be increased.

3 Detection of a bloom in its early stages will facilitate more economical control.

B Field Aspects of the Analysis Program

1 Two general aspects of plankton analysis are commonly recognized: quantitative and qualitative.

a Qualitative examination tells what is present.

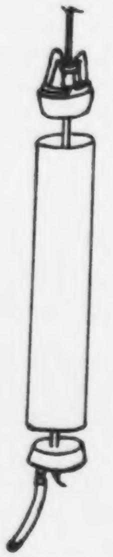
b Quantitative tells how much.

c Either approach is useful, a combination is best.

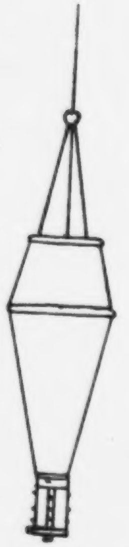
2 Equipment for collecting samples in the field is varied.

a A half-liter bottle will serve for surface samples of phytoplankton, if carefully taken.

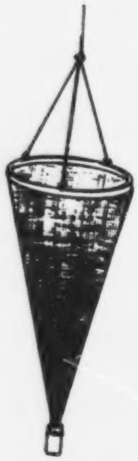
PLANKTON SAMPLERS

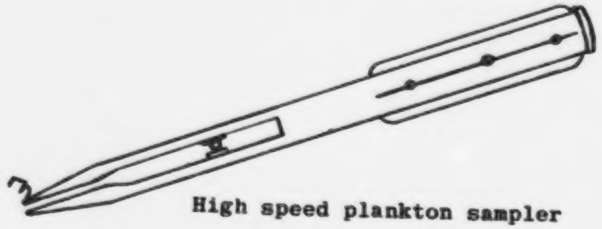


Kemmerer



Wisconsin net





High speed plankton sampler

PLATE IV

b A Kemmerer, Nansen, or other special sampler (small battery operated pumps are time saving) is suggested for depth samples.

c Plankton nets concentrate the sample in the act of collecting and also capture certain larger forms which escape from the bottles. Only the more elaborate types are quantitative however. For phytoplankton, #20 or #25 size nets are commonly used. Usually a net diameter of 5 - 10 inches is sufficient. The smaller forms however, are lost through any net.

C Zooplankton Collecting

1 Since zooplankton have the ability to swim away from water bottles, etc. nets towed at moderately fast speed are used for their capture. Number 12 nets (aperature size 0.119 mm, 125 meshes 1 inch) or smaller numbered net sizes are commonly used. A net diameter greater than 5" is preferred.

Frequently half meter nets or larger are employed. These may be equipped with flow measuring devices for measuring the amount of water entering the net.

2 Other instruments such as the Clark-Bumpus, Gulf-Stream, Hardy continuous plankton recorder, and high-speed instruments are used for collecting zooplankton, also.

3 The devices used for collecting plankton capture both the plant and animal types. The mesh size (net no.) is a method for selecting which category of plankton is to be collected.

D The Location of Sampling Points

1 Both shallow and deep samples are suggested.

a "Shallow" samples should be taken at a depth of 6 inches to one foot. The surface film is often significant.

b "Deep" samples should be taken at such intervals between surface and bottom as circumstances dictate. In general, the entire water column should be sampled as completely as practicable, and the plankton from each level recorded separately.

2 For estuarine plankton, it is necessary to sample different periods in the stage of the tide, otherwise samples would be biased to a given time, or type of water carried by the tidal currents.

3 Plankton is subjected to the force of the winds and currents. As a result, the plankton is often in patches or "wind rows" (Langmuir cells). For this reason when using a net, it is often desirable to tow the net at right angles to the wind or current.

4. Nearly all plankton are horizontally discontinuous. Planktonic organisms tend to be numerous near the bottom in daylight, but distributed more evenly through the water column at night. Therefore, a series of tows or samples at different depths is necessary to obtain a complete sampling. One technique often employed is to take an oblique tow from the bottom to the top of the water column.

5. Pilot studies to indicate sampling locations and intervals are often mandatory. Some studies require random sampling points.

6. The number of sampling stations that should be estabilshed is limited by the capability of the laboratory to analyze the samples, but should approach the needs of the objectives as closely as possible.

7 Field conditions greatly affect the plankton, and a record thereof should be carefully identified with the collection as in II above.

8 Provisions should be made for the field stabilization of the sample until the laboratory examination can be made if more than an hour or so is to elapse.

a Refrigeration or icing is very helpful, but ice should never be placed in the sample.

b Preservation by 5% formalin is widely used but badly shrinks animals and makes all forms brittle.

c Lugols solution is a good preservative.

d Ultra-violet sterilization is sometimes used in the laboratory to retard the decomposition of plankton.

e A highly satisfactory merthiolate preservative has been described by Weber (1968).

VII COLLECTING FISH AND OTHER NEKTON PLATES V, VI

A Fish and other nekton must be sought in the obscure and unlikely areas as well as the obvious locations in order for the collection to be complete. Several techniques should be employed wherever possible (this is appropriate for all biota). It is advisable to check with local authorities to inform them of the reasons for sampling, because many of the techniques are not legal for the layman. In this area, perhaps more than any other, professionally trained workers are important. Also, there must be at least one helper, as a single individual always has difficulty in pulling both ends of a 20 foot seine simultaneously! The more common techniques are listed below.

B Seines

1 Straight seines range from 4-6 feet and upwards in length. "Common sense" minnow seines with approximately 1/4 inch mesh are widely used along shore for collecting the smaller fishes.

2 Bag seines have an extra trap or bag tied in the middle which helps trap and hold fish when seining in difficult situations.

C Gill nets are of use in offshore and/or deep waters. They range in length from approximately 30 yards upward. A mesh size is designed to catch a specified size of fish. The trammel net is a variation of the gill net.

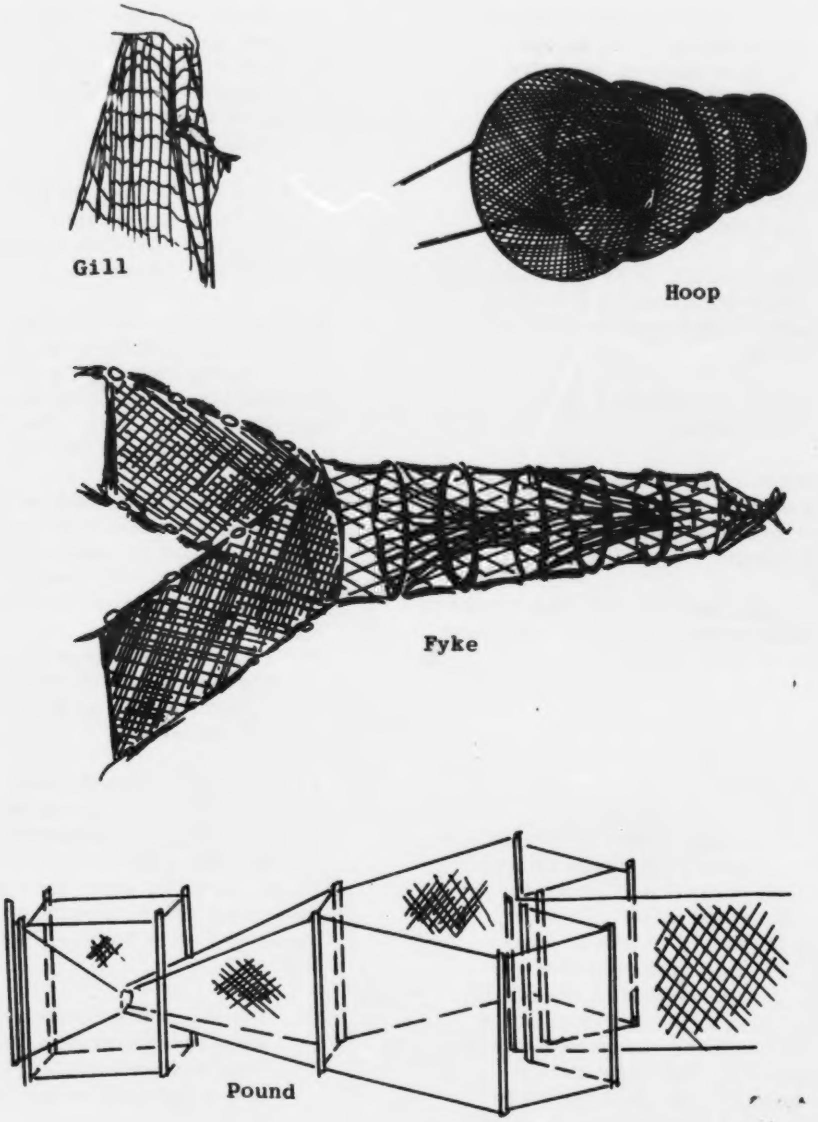
D Traps range from small wire boxes or cylinders with inverted cone entrances to semi-permanent weirs a half mile or more in length. All tend to induce fish to swim into an inner chamber protected by an inverted cone or V - shaped notch to prevent escape. Current operated rotating fish traps are also very effective (and equally illegal) in suitable situations.

E Trawls are submarine nets, usually of considerable size, towed by vessels at speeds sufficient to overtake and scoop in fish, etc. The mouth of the net must be held open by some device such as a long beam (beam trawl) or two or more vanes or "otter boards" (otter trawl). Plate III

1 Beam and otter trawls are usually fished on the bottom, but otter trawls when suitably rigged are now being used to fish mid-depths.

2 The midwater trawl resembles a huge plankton net many feet in diameter. It is proving very effective for collecting at mid-depths.

FISH NETS



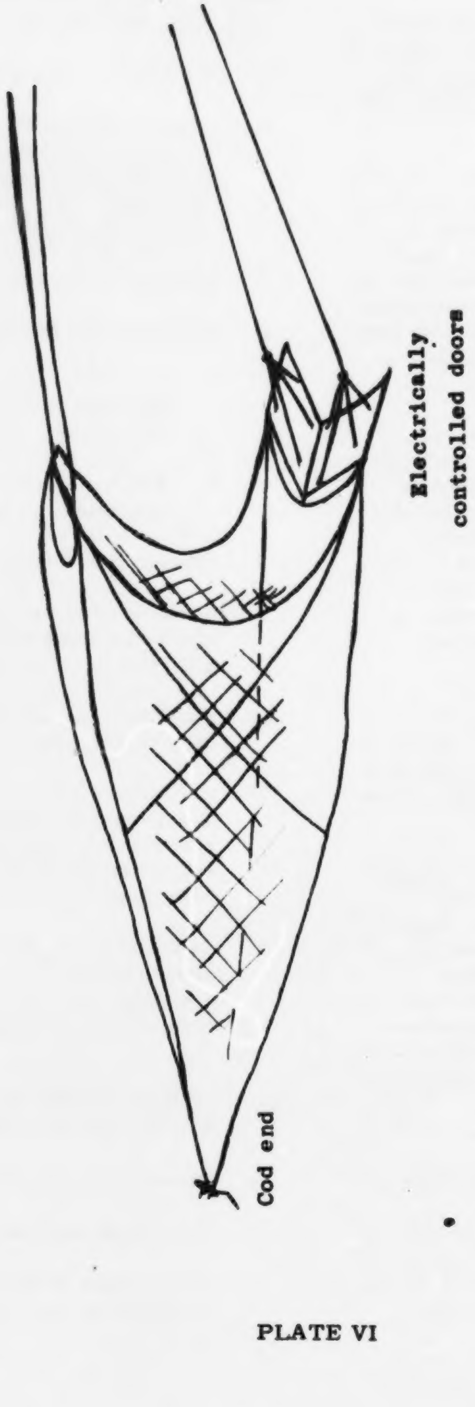
Gill

Hoop

Fyke

Pound

PLATE V


Electrically controlled doors
Cod end

MIDWATER TRAWL

PLATE VI

PLATE VI

Numerous special designs have been developed. Plate VI

F Electric seines and screens are widely employed by fishery workers in small and difficult streams. They may also be used in shallow water like areas with certain reservations.

G Poisoning is much used in fishery studies and management. Most widely used and generally satisfactory is rotenone in varying formulations, although many others have been employed from time to time, and some appear to be very good. Under suitable circumstances, fish may even be killed selectively according to species.

H Personal observation by competent personnel, and also informal inquiries and discussions with local residents will often yield information of real use. Many laymen are keen observers, although they do not always understand what they are seeing. The organized creel census technique yields data on what and how many fish are being caught.

I Angling remains in its own right a very good technique in the hands of the skilled practitioner, for determining what fish are present. Spear-fishing also is now being used in some studies.

J Fish and other nekton are often tagged to trace their movements during migration and at other times. Miniature radio transmitters can now be attached or fed to fish (and other organisms) which enable them to be tracked over considerable distances. Physiological information is often obtained in this way. This is known as telemetry.

VIII SPECIAL REQUIREMENTS ON BOATS

Handling biological collections (as contrasted to chemical and physical sampling) on board boats differs with the size of the craft and the magnitude of operations. Some possible items are listed below. Hoisting and many other types of gear are used in common with other types of collection, and will not be listed.

A Special Laboratory Room(s)

B Constant flow of Clean water for culturing organisms. (Selection of materials and design of a system to insure non-toxic water may be very troublesome but very important.)

C Live Box built into ship at water level

D Refrigeration System(s)

  1 For controlling temperature of experimental organisms in laboratory.

  2 For deep-freezing and storage of specimens to be examined later.

E Storage Space (Unrefrigerated)

F Facilities for the safe storage and use of microscopes and other laboratory equipment.

G Facilities for the safe storage and use of deck equipment.

H Administrative access to the Captain and Technical Leader in order to coordinate requirements for biological collection (such as a slow plankton tow) with those for other collections.

I Safety of personnel working in and around boats, as well as in other field activities should be seriously considered and promoted at all times.

IX OTHER TYPES OF BIOLOGICAL FIELD STUDIES INCLUDE

A Productivity Studies of Many Types

B Life Cycle and Management

C Distribution of Sport or (potentially) Commercial Species

D Scattering Layers and Other Submarine Sound Studies

E Artificial Culture of Marine Food Crops

F Radioactive Uptake

G Growth of Surface-Fouling Organisms

H Marine Borers

I Dangerous Marine Organisms

J Red Tides

K Others

X SOURCES OF COLLECTING EQUIPMENT

Many specialized items of biological collecting equipment are not available from the usual laboratory supply houses. Consequently, the American Society of Limnology and Oceanography has compiled a list of companies handling such items and released it as "Special Publication No. 1, Sources of Limnoligical and Oceanographic Apparatus and Supplies." Available from the Secretary of the Society.

XI SAFETY

The hazards associated with work on or near water require special consideration. Personnel should not be assigned to duty alone in boats, and should be competent in the use of boating equipment (courses are offered by the U. S. Coast Guard). Field training should also include instructions on the proper rigging and handling of biological sampling gear.

Life preservers(jacket type work vests) should be wron at all times when on or near deep water. Boats should have air-tight or foam-filled compartments for flotation and be equipped with fire extinguishers, running lights, oars, and anchor. The use of inflatable plastic or rubber boats is discouraged.

All boat trailers should have two rear running and stop lights and turn signals and a license plate illuminator. Trailers 80 inches (wheel to wheel) or more wide should be equipped with amber marker lights on the front and rear of the frame on both sides.

Laboratories should be provided with fire extinguishers, fume hoods, and eye fountains. Safety glasses should be worn when mixing dangerous chemicals and preservatives.

A copy of the EPA Safety Manual is available from the Office of Administration, Washington, D.C. (Reference: 10)

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Descriptors:

Aquatic Environment, Analytical Techniques, Sampling, On-Site Investigations, Preservation, Samplers, Water Sampling, Handling, Sample, Surface Waters, Aquatic Life

STREAM INVERTEBRATE DRIFT

I Invertebrates which are part of the benthos, but under certain conditions become carried downstream in appreciable numbers, are known as drift.

A Groups which have members forming a conspicuous part of the drift include the insect orders Ephemeroptera, Trichoptera, Plecoptera and the crustacean order Amphipoda.

B Other invertebrate groups exhibit drift patterns.

II THREE BASIC TYPES OF DRIFT ARE RECOGNIZED

A Catastrophic Drift

Floods wash numerous benthic organisms downstream. Application of pesticides may also cause such drift.

B Constant Drift (Incidental or Adventitious)

Organisms are constantly being dislodged from the substrate during normal activities and carried downstream.

C Periodic (Diel) or Behavioral Drift

In contrast to the other categories, this is a specific behavior pattern and related to circadian activity rhythms.

1 Seasonal drift occurs, for example, in some maturing stoneflies which drift downstream for emergence. This is another reason for a serious consideration of drift in bottom fauna sampling since such presence of stoneflies could easily be misinterpreted.

2 Periodic or diel drift occurs in peaks for successive 24-hour periods.

a Night-active. Light intensity is the phase-setting mechanism.

b Day-active. Water temperature appears to be the phase-setter.

III DIEL DRIFT

A Diel activity rhythms generally include two peaks during the 24-hour period; one major and the other minor.

1 The bigeminus type in which the major peak occurs first (after sunset).

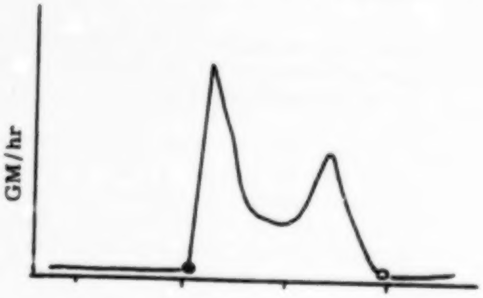

FIGURE 1

2 The alternans pattern with the major peak occurring last.

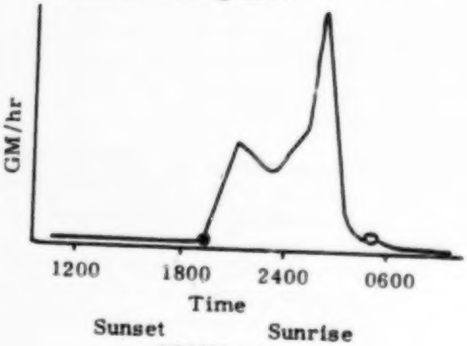

FIGURE 2

B Drift Rate and Density (Waters, 1969)

1 Drift rate defined is "...the quantity of organisms passing a width transect or portion thereof, per unit time;

it is a measure of displacement or the movement of organisms from one place to another."

2 Drift density "...is the quantity of organisms per unit volume of water, in much the same way as plankton density can be defined."

IV IMPLICATIONS FOR BIOLOGICAL SAMPLING

A The drift from productive upstream reaches may support a fish population existing in relatively barren stream sections.

B Drift will colonize artificial substrates, such as suspended rock baskets, when placed in such habitats.

C A bottom sampler such as the Surber, could also be sampling drift when only resident benthic organisms are intended to be collected. This would depend on the hour of collection and length of time the Surber sampler is in the water.

D Application of drift studies have been widely used in pesticide related studies. In conjunction with such studies, Dimond concluded that:

1 The status of drift is a much better indicator of the steady state and of total productivity than is the status of the bottom fauna.

2 Bottom sampling, however, is superior when analyzing survival and recovery of the quality of population.

3 A combination of both in such a sampling program would be most likely to yield the most useful data.

E Drift sampling techniques have been useful for recovery of large numbers of sand-dwelling mayflies, which were once rarely collected.

V MAJOR TAXA INVOLVED IN DRIFT

A The crustacean order Amphipoda

1 Gammarus species

2 Hyalella azteca

B The Insect Orders

1 Ephemeroptera

Baetis species (apparently universal)

2 Plecoptera

3 Trichoptera

4 Diptera
Simuliidae

5 Elmidae

C The main groups exhibiting very high drift rates include: Baetis, some Gammarus species, and some Simuliidae.

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ARTIFICIAL SUBSTRATES

I INTRODUCTION: THE NATURE OF ARTIFICIAL SUBSTRATES

A Artificial substrates are anything deliberately placed in the water for the purpose of providing a place for benthic or attached (sessile, sedentary, etc.) organisms to grow on or in. This is in contrast to "bait" which is used as an attractant.

B Their origins for commercial use, or human food production are rooted in antiquity. Some examples are:

1 Ropes, poles, brush, concrete structures, and other objects thrust into the bottom, or suspended in estuarine waters to catch and grow oysters and mussels (cultural techniques), known virtually around the world.

2 Straw or reed tepees planted in shallow alkaline lakes (in Mexico for example) to catch the eggs of Corixids (Insecta: Order Hemiptera, back-swimmers). Eggs are harvested by drying and brushing them off onto white sheets. Used for human food.

C The fouling of ships bottoms, piling, etc. by barnacles and other marine life is an "artificial substrate in reverse".

D The use of aggregate to support a zoogloeal mass of micro-biota in a trickling filter, thus simulating a riffle area in a surface stream, is a modern concept to harness and make use of "consumer" and "reducer" elements of a community in order to dissipate the energy (oxidize, exhaust the food value) contained in sewage.

II ECOLOGICAL BASIS

A Artificial substrates are based on the "laws of organismal distribution."

1 Any given kind of organisms tends to be present (inhabit) in all available suitable habitats.

2 Any given habitat tends to be inhabited by all suitably adapted kinds of organisms.

B A "substrate" being an object (or group of objects) constitutes a habitat suitable for sessile or attached organisms, and also those that naturally burrow in, crawl over, or otherwise live associated with objects. Natural objects here could mean the bottom, stones, sticks (floating or sunk), etc.

C Organisms that would not be attracted to substrates would be plankton and nekton (fish and larger swimming invertebrates).

D Ecological Succession

Colonization is rapid in a biologically productive water, and normally reaches a stable climax* community in about a month. A typical outline of successive forms to appear in a freshwater situation, for example, might be as follows.

1 Periphyton (slime forming) stage (see also below)

a Bacteria - within an hour

b Diatoms - within the first day

c Other micro-algae - within the first day

d Protozoa - within the first day

2 Macroinvertebrate dominated stage (see also below)

a Primary attached or sedentary colonizers - second to third day

1) Net caddisflies

2) Bryozoa

3) Cordylophora caspia

4) Hydra

---

*A community which has achieved a point of no further change, under a given set of environmental conditions. Time scale may vary with circumstances.

NOTE: Mention of commercial products and manufacturers does not imply endorsement by the Environmental Protection Agency.

b Primary foragers

1) Mayflies

2) Stoneflies

3) Midges

c Secondary attached or sedentary colonizers:

1) Sponges

2) Filamentous algae

d Adventitious forms

1) Crustaceans

2) Flatworms

3) Leeches

4) Snails

5) Other

3 Artificial substrates in a marine environment proceed through similar stages, except that the macroinvertebrate stage may be more subject to variation in the attachment of broods of barnacle, oyster, and other larvae resulting from greater numbers of types present, tidal current variation, meteorological conditions, etc.

III ARTIFICIAL SUBSTRATES AS SCIENTIFIC COLLECTING DEVICES

A A review of the history of artificial substrates for collecting microorganisms (aufwuchs) (Cooke, 1956) indicates that glass microscope slides were first used for this purpose about 1915. Wood or metal panels appear, however, to have been deliberately exposed for the scientific collection of larger organisms at least since approximately the turn of the century, and probably long before that (Visscher, 1928).

B Biological Applications

The principles of the artificial substrate remain the same, regardless of the community sampled. Two general types of communities and associated samplers have been employed:

1 Periphyton (or aufwuchs) samplers

Periphyton is the community of slime forming microorganisms which is the first to attach to objects newly exposed under water. This community is generally considered to provide an anchor layer to which other higher forms of life can more readily attach. It tends to persist until overgrown or displaced by larger organisms, and then in turn can be found spreading over the surfaces of these same larger plants and animals.

2 Periphyton has been widely studied as it appears on 1 × 3 glass microscope slides which are equally convenient to expose in the field and to study in the laboratory.

3 Particular studies have included:

a The original bacterial and fungal slime

b Diatom identification and counts

c Identification and counts of other microscopic algae

d Protozoans

e Primary productivity

4 The macroinvertebrate community is sampled by a great variety of devices such as those cited below. The organisms are usually removed from the substrate for study. Applications have included the following:

a General study of the macroinvertebrate community b Estimates of productivity

c Studies of the life cycle of particular species

d Studies of the influence of the substrate on the attachment of sessile forms

1) The influence of toxic paints for the prevention of fouling organisms

2) Wood panels to study the penetration of boring molluscs and crustaceans

C Effect of type of device on what is collected

1 Wood boring organisms like teredo worms (Mollusca, Pelecypoda) or gribbles (Arthropoda, Isopoda) would obviously be attracted primarily to wood (although some are known to bore in other materials).

2 Delicate forms and crawling forms would be most likely to be collected on devices having a shape to protect against strong currents.

3 Those with strong attachments could endure swift currents; often, surprisingly, even during periods of original attachment (ex. byssus attached clams which are also benthic forms).

4 Bottom burrowers would be most likely collected in artificially contained portions of bottom material.

D Effect of Location

1 The depth at which a sampler is suspended may influence the organisms attracted.

2 Location in or out of a current, direct sunlight, etc., will influence the take.

E Some Types of Devices

1 Cement plates, panels, and blocks

2 Ceramic tiles

3 Wood blocks

4 Metal plates

5 Glass slides - 1 × 3 inch micro slides are used by many workers. Numerous devices are employed to hold them. They are generally either floated (Weber and Raschke 1966) or suspended in racks, anchored to submerged bricks or other objects.

6 Plastic petri dishes

Burbanck and Spoon utilized an ordinary 50 × 12 mm plastic petri dish for collecting sessile protozoa. Sickle modified this by using a styrofoam cup (6 oz. size) with the bottom third being cut off. The lower unit of the plastic dish is easily wedged into place in the cup and the device is simply held by a nylon line on a rope held in place by an appropriate anchor and float.

The cup which tends to float is so held that the petri dish bottom is in a horizontal position and bottom side up.

7 Multiple plate (Hester and Dendy, 1962)

a Common current procedure utilizes 3-inch squares of 1/4 inch thick Masonite separated by 1-inch square spacers.

These may be:

b Threaded on an eye bolt or long rod.

c Suspended by a loop of nylon cord.

8 Baskets or trays of bottom-type material

a Trays of bottom material sunk in the surface layer of the bottom.

b Baskets of stones suspended in the water (Anderson and Mason, 1966).

9 Boxes, cages, bundles, etc., of brush, reeds, or artificial material.

10 Polyethylene tapes

11 Plastic webbing

Minnesota Mining and Manufacturing Company conservation web no. 200.

12 Styrofoam

13 Glass coverslips

Small slips are floated on the surface of the water. Highly useful for protozoa and rotifers. Remove and place on a micro slide. Examine as a wet mount.

F Retrieval is an acute problem with all of these samplers.

1 Physical factors

a Relocation

b Floods and drift

c High water

2 Well marked samplers or floats are naturally vulnerable to the public, resulting in disturbed, damaged, or destroyed sample gear.

a This has been overcome by an ingenious submerged float and recovery line device. The weak link in a submerged recovery line is a modified flash bulb. An electronic device actuated by an underwater gun breaks the bulb allowing the float and attached line to surface. (Ziebell, McConnell, and Baldwin)

b This unit has been further modified by Fox (University of Georgia Cooperative Fishery Unit) who used an inexpensive detonator, "Seal Salute". The latter is an inexpensive fused charge designed for underwater explosion.

IV ARTIFICIAL SUBSTRATES OR SAMPLERS, AND WATER QUALITY

A Artificial substrates provide a habitat ("place to live"). It follows from the laws of distribution (II A 1 and 2 above), that the community which inhabits a device will be governed by the physical nature or structure interacting with the characteristics of the surrounding water (velocity, temperature, chemical characteristics, etc.). Since the nature of the sampler is controlled, it is evident that the characteristics of the water constitute the variable factor.

B Water Quality Surveillance

1 Similar substrates suspended side by side in the same water tend to accumulate (essentially) the same communities and quantities of organisms.

2 Similar substrates suspended in different waters accumulate different communities and quantities.

3 Ergo: different communities and quantities collected from similar substrates at different places and times, probably indicate different water qualities.

a These may be natural (seasonal, diurnal, etc.)

b Or they may be a result of human influences (pollution)

c A series of samplers the length of a stream, lake, or estuary can suggest "steady state" differences in water quality.

d A series of samplers exposed over a period of time at a given site can suggest changes of water quality in time.

4 The artificial substrate thus essentially constitutes an in-situ bioassay of the water.

C Interpretation and Significance of Collections

1 The unit of comparison is most appropriately taken as "the sampler". The artificial substrate by definition is not the natural local bottom material, and unless it consists of a portion of that bottom which has been actually removed and replaced in an artificial container (III-D-7) the composition and magnitude of the community it contains may or may not bear a definitive relationship to the actual natural problem. The take of the artificial substrate thus may have relatively little relationship to the take of a Petersen or an Ekman grab (dredge).

2 Comparisons between different types of samplers are likewise hazardous. Each is what it is, and if they are different they are not identical; thus the biota each collects cannot be expected to be identical (CF: II A).

3 Artificial substrates should generally be compared on a "sampler vs sampler" basis, or for periphyton, "unit area vs unit area".

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ATTACHED GROWTHS
(Periphyton or Aufwuchs)

I The community of attached microscopic plants and animals is frequently investigated during water quality studies. The attached growth community (periphyton) and suspended growth community (plankton) are the principal primary producers in waterways--they convert nutrients to organic living materials and store light originating energy through the processes of photosynthesis. In extensive deep waters, plankton is probably the predominant primary producer. In shallow lakes, ponds, and rivers, periphyton is the predominant primary producer. During the past two decades, investigators of microscopic organisms have increasingly placed emphasis on periphytic growths because of inherent advantages over the plankton when interpreting data from surveys on flowing waters:

A Blum (1956) "....workers are generally agreed that no distinctive association of phytoplankton is found in streams, although there is some evidence of this for individual zooplankters (animals) and for a few individual algae and bacteria. Plankton organisms are often introduced into the current from impoundments, backwater areas or stagnant arms of the stream.... Rivers whose plankton is not dominated by species from upstream lakes or ponds are likely to exhibit a majority of forms which have been derived from the stream bottom directly and which are thus merely facultative or opportunistic plankters. "

B "The transitory nature of stream plankton makes it nearly impossible to ascertain at which point upstream agents producing changes in the algal population were introduced, and whether the changes occurred at the sampling site or at some unknown point upstream. In contrast, bottom algae (periphyton) are true components of the stream biota. Their sessile-attached mode of life subjects them to the quality of water continuously flowing over them. By observing the longitudinal distribution of bottom algae within a stream, the sources of the agents producing the change can be traced (back-tracked)" (Keup, 1966).

II TERMINOLOGY

A Two terms are equally valid and commonly in use to describe the attached community of organisms. Periphyton literally means "around plants" such as the growths overgrowing pond-weeds; through usage this term means the attached film of growths that rely on substrates as a "place-to-grow" within a waterway. The components of this growth assemblage consists of plants, animals, bacteria, etc. Aufwuchs is an equally acceptable term [probably originally proposed by Seligo (1905)]. Aufwuchs is a German noun without equivalent english translation; it is essentially a collective term equivalent to the above American (Latin root) term - Periphyton. (For convenience, only, PERIPHYTON, with its liberal modern meaning will be used in this outline.)

B Other terms, some rarely encountered in the literature, that are essentially synonymous with periphyton or describe important and dominant components of the periphytic community are: Nereiden, Bewuchs, Laison, Belag, Besatz, attached, sessile, sessile-attached, sedentary, seeded-on, attached materials, slimes, slime-growths, and coatings.

The academic community occasionally employs terminology based on the nature of the substrates the periphyton grows on (Table 1).

TABLE 1

Periphyton Terminology Based on Substrate Occupied

Substrate	Adjective
various	epiholitic, nereiditic, sessile
plants	epiphytic
animals	epizooic
wood	epidendritic, epixylonic
rock	epilithic

[After Srameck-Husek (1946) and via Sladeckova (1962)] Most above listed latin-root adjectives are derivatives of nouns such as epihola, epiphyton, spizoa, etc.

III Periphyton, as with all other components of the environment, can be sampled qualitatively (what is present) and quantitatively (how much or many are present).

A Qualitative sampling can be performed by many methods and may extend from direct examination of the growths attached to a substrate to unique "cuttings" or scrapings. It may also be a portion of quantitative sampling.

B Quantitative sampling is difficult because it is nearly impossible to remove the entire community from a standardized or unit area of substrate.

1 Areas scraped cannot be determined precisely enough when the areas are amorphous plants, rocks or logs that serve as the principal periphyton substrates.

2 Collection of the entire community within a standard area usually destroys individual specimens thereby making identification difficult (careful scraping can provide sufficient intact individuals of the species present to make qualitative determinations); or the process of collection adds sufficient foreign materials (i. e. detritus, substrate, etc.) so that some commonly employed quantitative procedures are not applicable.

IV Artificial substrates are a technique designed to overcome the problems of direct sampling. They serve their purpose, but cannot be used without discretion. They are objects standardized as to surface area, texture, position, etc. that are placed in the waterway for pre-selected time periods during which periphytic growths accumulate. They are usually made of inert materials, glass being most common with plastics second in frequency. Over fifty various devices and methods of support or suspension of the substrates have been devised (Sladeckova, 1962) (Weber, 1966) (Thomas, 1968).

V ARTIFICIAL SUBSTRATE PLACEMENT

A Position or Orientation

1 Horizontal - Includes effects of settled materials.

2 Vertical - Eliminates many effects of settled materials.

B Depth (light) - A substrate placed in lighted waters may not reflect conditions in a waterway if much of the natural substrate (bottom) does not receive light or receives light at reduced intensity. (Both excessive light and a shortage of light can inhibit growths and influence the kinds of organisms present.)

C Current is Important

1 It can prevent the settling of smothering materials.

2 It flushes metabolic wastes away and introduces nutrients to the colony.

VI THE LENGTH OF TIME THE SUBSTRATE IS EXPOSED IS IMPORTANT.

A The growths need time to colonize and develop on the recently introduced substrate.

B Established growths may intermittently break-away from the substrate because of current or weight induced stresses, or "over-growth" may "choke" the attachment layers (nutrient, light, etc. restrictions) which then weaken or die allowing release of the mass.

C A minimum of about ten days is required to produce sufficient growths on an artificial substrate; exposures exceeding a longer time than 4-6 weeks may produce "erratic results" because of sloughing or the accumulation of senile growths in situations where the substrate is artificially protected from predation and other environmental stresses.

VII Determining the variety of growths present is presently only practical with microscopic examination. (A few micro-chemical procedures for differentiation show promise--but, are only in the early stages of development.)

VIII DETERMINING THE QUANTITY OF GROWTH(S)

A Direct enumeration of the growths while attached to the substrate can be used, but is restricted to the larger organisms because (1) the problem of maintaining material in an acceptable condition under the short working distances of the objective lenses on compound microscopes, and (2) transmitted light is not adequate because of either opaque substrates and/or the density of the colonial growths.

B Most frequently, periphyton is scraped from the substrate and then processed according to several available procedures, the selection being based on the need, and use of the data.

1 Aliquots of the sample may be counted using methods frequently employed in plankton analysis.

a Number of organisms

b Standardized units

c Volumetric units

d Others

2 Gravimetric

a Total dry weight of scrapings

b Ash-free dry weight (eliminates inorganic sediment)

c A comparison of total and ash-free dry weights

3 Volumetric, involving centrifugation of the scrapings to determine a packed biomass volume.

4 Nutrient analyses serve as indices of the biomass by measuring the quantity of nutrient incorporated.

a Carbon

1) Total organic carbon

2) Carbon equivalents (COD)

b Organic nitrogen

c Phosphorus - Has limitations because cells can store excess above immediate needs.

d Other

5 Chlorophyll and other bio-pigment extractions.

6 Carbon-14 uptake

7 Oxygen production, or respiratory oxygen demand

IX EXPRESSION OF RESULTS

A Qualitative

1 Forms found

2 Ratios of number per group found

3 Frequency distribution of varieties found

4 Autotrophic index (Weber)

5 Pigment diversity index (Odum)

B Quantitative

1 Areal basis--quantity per square inch, foot, centimeter, or meter. For example:

a 16 mgs/sq. inch

b 16,000 cells/sq. inch

2 Rate basis. For example:

a 2 mgs/day, of biomass accumulation

b 1 mg O_2/mg of growth/hour

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APPLICATION OF BIOLOGICAL DATA

I ECOLOGICAL DATA HAS TRADITIONALLY BEEN DIVIDED INTO TWO GENERAL CLASSES:

A Qualitative - dealing with the taxonomic composition of communities

B Quantitative - dealing with the population density or rates of processes occurring in the communities

Each kind of data has been useful in its own way.

II QUALITATIVE DATA

A Certain species have been identified as:

1 Clean water (sensitive) or oligotrophic

2 Facultative, or tolerant

3 Preferring polluted regions (see: Fjerdinstad 1964, 1965; Gaufin & Tarzwell 1956; Palmer 1963, 1969; Rawson 1956; Teiling 1955)

B Using our knowledge about ecological requirements the biologist may compare the species present

1 At different stations in the same river (Gaufin 1958) or lake (Holland 1968)

2 In different rivers or lakes (Robertson and Powers 1967)

or changes in the species in a river or/lake over a period of several years. (Carr & Hiltunen 1965; Edmondson & Anderson 1956; Fruh, Stewart, Lee & Rohlich 1966; Hasler 1947).

C Until comparatively recent times taxonomic data were not subject to statistical treatment.

III QUANTITATIVE DATA: Typical Parameters of this type include:

A Counts - algae/ml; benthos/m^2; fish/net/day

B Volume - mm^3 algae/liter

C Weight - dry wgt; ash-free wgt.

D Chemical content - chlorophyll; carbohydrate; ATP; DNA; etc.

E Calories (or caloric equivalents)

F Processes - productivity; respiration

IV Historically, the chief use of statistics in treating biological data has been in the collection and analysis of samples for these parameters. Recently, many methods have been devised to convert taxonomic data into numerical form to permit:

A Better communication between the biologists and other scientific disciplines

B Statistical treatment of taxonomic data

C In the field of pollution biology these methods include:

1 Numerical ratings of organisms on the basis of their pollution tolerance

(saprobic valency: Zelinka & Sladecek 1964)

(pollution index: Palmer 1969)

2 Use of quotients or ratios of species in different taxonomic groups (Nygaard 1949)

3 Simple indices of community diversity:

a Organisms are placed in taxonomic groups which behave similarly under the same ecological conditions. The number of species in these groups found at "healthy" stations is compared to that found at "experimental" stations. (Patrick 1950)

b A truncated log normal curve is plotted on the basis of the number of individuals per diatom species. (Patrick, Hohn, & Wallace 1954)

c Sequential comparison index. (Cairns, Albough, Busey & Chanay 1968). In this technique, similar organisms encountered sequentially are grouped into "runs".

$$SCI = \frac{\text{runs}}{\text{total organisms examined}}$$

d Ratio of carotenoids to chlorophyll in phytoplankton populations:

OD_{430}/OD_{665} (Margalef 1968)

OD_{435}/OD_{670} (Tanaka, et al 1961)

e The number of diatom species present at a station is considered indicative of water quality or pollution level. (Williams 1964)

f $\frac{\text{number of species (S)}}{\text{number of individuals (N)}}$

g $\frac{\text{number of species (S)}}{\text{square root of number of individuals } (\sqrt{N})}$

h $\frac{S - 1}{\log_e N}$ (Menhinick 1964)

i $d = \frac{\Sigma n_i (n_i - 1)}{N (N - 1)}$ (Simpson 1949)

where n_i = number of individuals belonging to the i-th species, and

N = total number of individuals

j Information theory:

The basic equation used for information theory applications was developed by Margalef (1957).

$$I = \frac{1}{N} \log_2 \frac{N!}{N_a!\,N_b!\ldots N_s!}$$

where I - information/individual; N_a, $N_b \ldots N_s$ are the number of individuals in species a, b, ... s, and N is their sum.

This equation has also been used with:

1) The fatty acid content of algae (McIntire, Tinsley, and Lowry 1969)

2) Algal productivity (Dickman 1968)

3) Benthic biomass (Wilhm 1968)

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USING BENTHIC BIOTA IN WATER QUALITY EVALUATIONS

I BENTHOS ARE ORGANISMS GROWING ON OR ASSOCIATED PRINCIPALLY WITH THE BOTTOM OF WATERWAYS

Benthos is the noun.

Benthonic, benthal and benthic are adjectives.

II THE BENTHIC COMMUNITY

A Composed of a wide variety of life forms that are related because they occupy "common ground"--the waterways bottom substrates. Usually they are attached or have relatively weak powers of locomotion. These life forms are:

1 Bacteria

A wide variety of decomposers work on organic materials, breaking them down to elemental or simple compounds (heterotrophic). Other forms grow on basic nutrient compounds or form more complex chemical compounds (autotrophic).

2 Algae

Photosynthetic plants having no true roots, stems, and leaves. The basic producers of food that nurtures the animal components of the community.

3 Flowering Aquatic Plants (Pondweeds)

The largest flora, composed of complex and differentiated tissues. Many are rooted.

4 Microfauna

Animals that pass through a U.S. Standard Series No. 30 sieve, but are retained on a No. 100 sieve. Examples are rotifers and microcrustaceans. Some forms have organs for attachment to substrates, while others burrow into soft materials or occupy the interstices between rocks, floral or faunal materials.

5 Meiofauna

Animals, mostly metazoans, that can pass a 1.0 mm to 0.5 mm screen. Examples are naiad worms and flatworms.

6 Macrofauna

Animals that are retained on a No. 30 sieve. This group includes the insects, worms, molluscs, and occasionally fish. Fish are not normally considered as benthos, though there are bottom dwellers such as sculpins and darters.

B It is a self-contained community, though there is interchange with other communities. For example: Plankton settles to it, fish prey on it and lay their eggs there, terrestrial detritus leaves are added to it, and many aquatic insects migrate from it to the terrestrial environment for their mating cycles.

C It is a stationary water quality monitor. The low motility of the biotic components requires that they "live with" the quality changes of the over-passing waters. Changes imposed in the long-lived components remain visible for extended periods, even after the cause has been eliminated. Only time will allow a cure for the community by drift and reproduction.

III HISTORY OF BENTHIC OBSERVATIONS

A Ancient literature records the vermin associated with fouled waters.

B 500-year-old fishing literature refers to animal forms that are fish food and used as bait.

C The scientific literature associating biota to water pollution problems is over 100 years old (Mackenthun and Ingram, 1964).

D Early this century, applied biological investigations were initiated.

  1 The entrance of State boards of Health into water pollution control activities.

  2 Creation of state conservation agencies.

  3 Industrialization and urbanization.

  4 Growth of limnological programs at universities.

E A decided increase in benthic studies occurred in the 1950 decade, and much of today's activities are strongly influenced by developmental work conducted during this period. Some of the reasons for this are:

  1 Movement of the universities from "academic biology" to applied pollution programs.

  2 Entrance of the federal government into enforcement aspects of water pollution control.

  3 A rising economy and the development of federal grant systems.

  4 Environmental Protection Programs are a current stimulus.

IV WHY THE BENTHOS?

A It is a natural monitor

B The community contains all of the components of an ecosystem.

  1 Reducers

  2 Producers

  3 Consumers

    a Detritivores and bacterial feeders

    b Herbivores

    c Predators

C Economy of Survey

  1 Manpower

  2 Time

  3 Equipment

D Extensive Supporting Literature

E Advantages of the Macrobenthos

  1 Relatively sessile

  2 Life history length

  3 Fish food organisms

  4 Reliability of Sampling

  5 Dollars/information

  6 Predictability

  7 Universality

V REACTIONS OF THE COMMUNITY TO POLLUTANTS

A Destruction of Organism Types

  1 Beginning with the most sensitive forms, pollutants kill in order of sensitivity until the most tolerant form is the last survivor. This results in a reduction of variety or diversity of organisms.

  2 The usual order of macroinvertebrate disappearance on a sensitivity scale below pollution sources is shown in Figure 2.

Water Quality Deteriorating ↓	Stoneflies Mayflies Caddisflies Amphipods Isopods Midges Oligochaetes	↑ Water Quality Improving

As water quality improves, these reappear in the same order.

B The Number of Survivors Increase

1 Competition and predation are reduced between forms.

2 When the pollutant is a food (plants, fertilizers, animals, organic materials)

C The Number of Survivors Decrease

1 The material added is toxic or has no food value.

2 The material added produces toxic conditions as a byproduct of decomposition (e.g., large organic loadings produce an anaerobic environment resulting in the production of toxic sulfides, methanes, etc.)

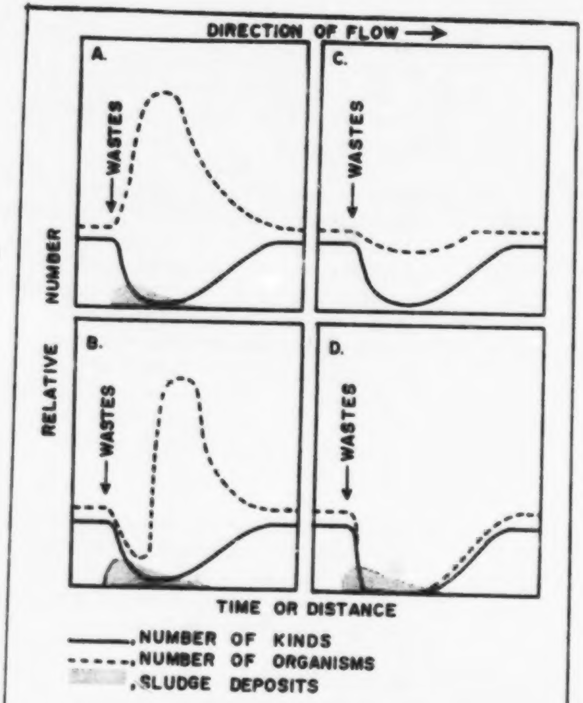
D The Effects May be Manifest in Combinations

1 Of pollutants and their effects.

2 Vary with longitudinal distribution in a stream. (Figure 1)

E Tolerance to Enrichment Grouping (Figure 2)

Flexibility must be maintained in the establishment of tolerance lists based on the response of organisms to the environment because of complex relationships among varying environmental conditions. Some general tolerance patterns can be established. Stonefly nymphs, mayfly naiads, hellgrammites, and caddisfly larvae represent a grouping (sensitive or intolerant) that is generalized quite sensitive to environmental changes. Blackfly larvae, scuds, sowbugs, snails, fingernail clams, dragonfly nymphs, damselfly nymphs, and most kinds of midge larve are intermediate (facultative or intermediate) in tolerance. Sludge-worms, some kinds of midge larvae (bloodworms), and some leeches are tolerant to comparatively heavy loads of organic pollutants. Sewage mosquitoes and rat-tailed maggots are tolerant of anaerobic environments.



Four basic responses of bottom animals to pollution. A. Organic wastes eliminate the sensitive bottom animals and provide food in the form of sludges for the surviving tolerant forms. B. Large quantities of decomposing organic wastes eliminate sensitive bottom animals and the excessive quantities of byproducts of organic decomposition inhibit the tolerant forms; in time, with natural stream purification, water quality improves so that the tolerant forms can flourish, utilizing the sludges as food. C. Toxic materials eliminate the sensitive bottom animals; sludge is absent and food is restricted to that naturally occurring in the stream, which limits the number of tolerant surviving forms. Very toxic materials may eliminate all organisms below a waste source. D. Organic sludges with toxic materials reduce the number of kinds by eliminating sensitive forms. Tolerant survivors do not utilize the organic sludges because the toxicity restricts their growth.

Figure 1

F Structural Limitations

1 The morphological structure of a species limits the type of environment it may occupy.

a Species with complex appendages and exposed complicated respiratory structures, such as stonefly nymphs, mayfly nymphs, and caddisfly larvae, that are subjected to a constant deluge of setteable particulate matter soon abandon the polluted area because of the constant preening required to maintain mobility or respirotory functions; otherwise, they are soon smothered.

b Benthic animals in depositing zones may also be burdened by "sewage fungus" growths including stalked protozoans. Many of these stalked protozoans are host specific.

2 Species without complicated external structures, such as bloodworms and sludgeworms, are not so limited in adaptability.

a A sludgeworm, for example, can burrow in a deludge of particulate organic matter and flourish on the abundance of "manna."

b Morphology also determines the species that are found in riffles, on vegetation, on the bottom of pools, or in bottom deposits.

VI SAMPLING PROCEDURES

A Fauna

1 Qualitative sampling determines the variety of species occupying an area. Samples may be taken by any method that will capture representatives of the species present. Collections from such samplings indicate changes in the environment, but generally do not accurately reflect the degree of change. Mayflies, for example, may be reduced from 100 to 1 per square foot. Qualitative data would indicate the presence of both species, but might not necessarily delineate the change in predominance from mayflies to sludgeworms. The stop net or kick sampling technique is often used.

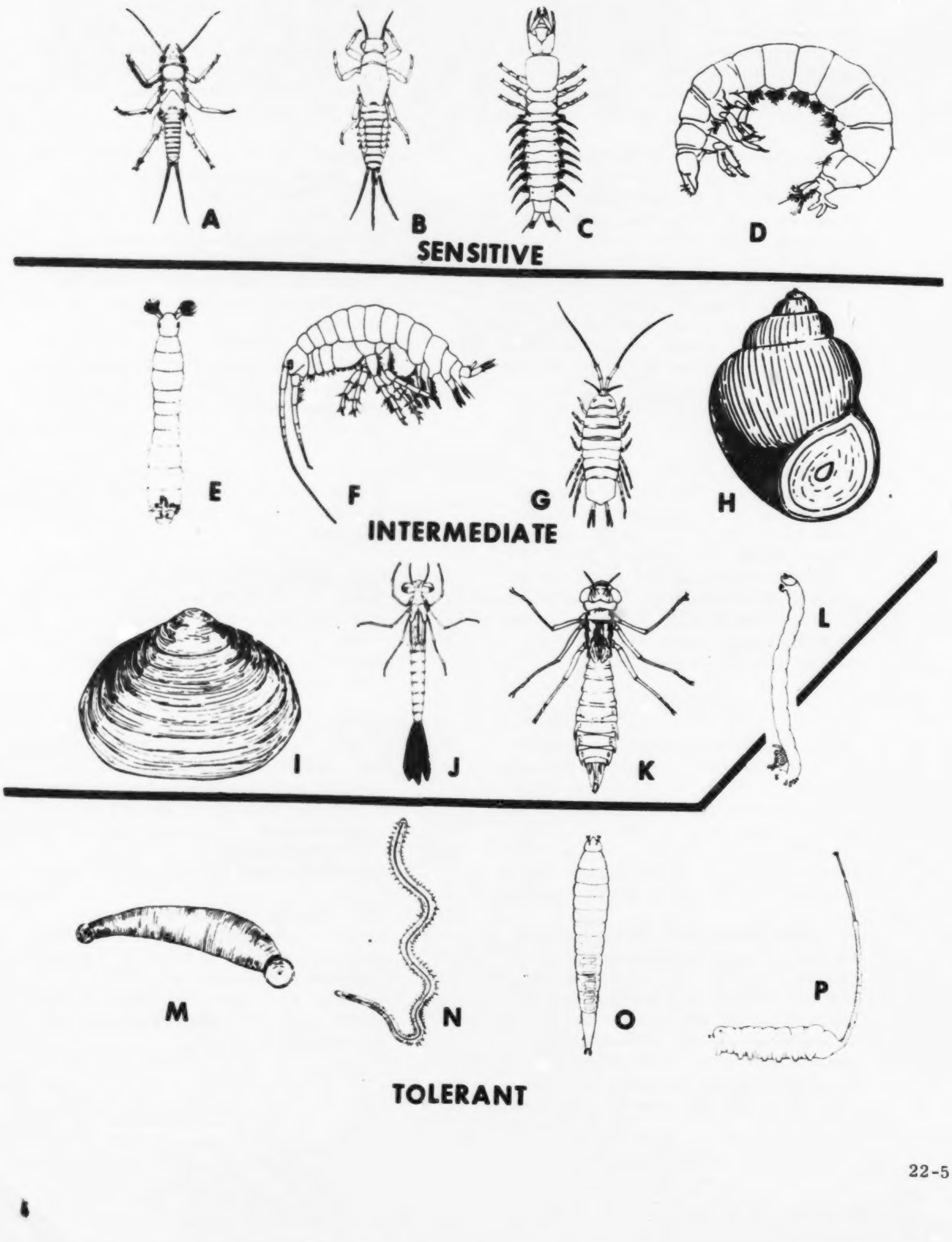
2 Quantitative sampling is performed to observe changes in predominance. The most common quantitative sampling tools are the Petersen and Elkman

REPRESENTATIVE BOTTOM-DWELLING MACROANIMALS

Drawings from Geckler, J., K. M. Mackenthun and W. M. Ingram, 1963. Glossary of Commonly Used Biological and Related Terms in Water and Waste Water Control, DHEW, PHS, Cincinnati, Ohio, Pub. No. 999-WP-2.

A	Stonefly nymph	(Plecoptera)
B	Mayfly nymph	(Ephemeroptera)
C	Hellgrammite or Dobsonfly larvae	(Megaloptera)
D	Caddisfly larvae	(Trichoptera)
E	Black fly larvae	(Simuliidae)
F	Scud	(Amphipoda)
G	Aquatic sowbug	(Isopoda)
H	Snail	(Gastropoda)
I	Fingernail clam	(Sphaeriidae)
J	Damselfly nymph	(Zygoptera)
K	Dragonfly nymph	(Anisoptera)
L	Bloodworm or midge fly larvae	(Chironomidae)
M	Leech	(Hirudinea)
N	Sludgeworm	(Tubificidae)
O	Sewage fly larvae	(Psychodidae)
P	Rat-tailed maggot	(Tubifera-Eristalis)

KEY TO FIGURE 2


A
B
C
D
SENSITIVE
E
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INTERMEDIATE
I
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K
L
M
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O
P
TOLERANT

grabs and the Surber stream bottom or square-foot sampler. Of these, the Petersen grab samples the widest variety of substrates. The Ekman grab is limited to fine-textured and soft substrates, such as silt and sludge.

The Surber sampler is designed for sampling riffle areas; it requires moving water to transport dislodged organisms into its net and is limited to depths of two feet or less.

3 The collected sample is screened with a standard sieve to concentrate the organisms; these are sorted from the retained material, and the number of each kind determined. Data are then adjusted to number per unit area, usually to number of bottom per square meter.

4 Independently, neither qualitative not quantitative data suffice for thorough analyses of environmental conditions. A cursory examination to detect damage may be made with either method, but a combination of the two gives a more precise determination. If a choice must be made, quantitative sampling would be best, because it incorporates a partial qualitative sample.

B Flora

1 Direct quantitative sampling of naturally growing bottom algae is difficult. It is basically one of collecting algae from a standardor uniform area of the bottom substrates without disturbing the delicate growths and thereby distort the sample. Indirect quantitative sampling is the best available method.

Artificial substrates, such as wood blocks, glass or plexiglass slides, bricks, etc., are placed in a stream. Bottom-attached algae will grow on these artificial substrates. After two or more weeks, the artificial substrates are removed for analysis. Algal growths are scraped from the substrates and the qunatity measured.

Since the exposed substrate area and exposure periods are equal at all of the sampling sites, differences in the quantity of algae can be related to changes in the quality of water flowing over the substrates.

2 The quantity of algae on artificial substrates can be measured in several ways. Microscopic counts of algal cells and dry weight of algal material are long established methods.

Microscopic counts involve thorough scraping, mixing, and suspension of the algal cells. From this mixture an aliquot of cells is withdrawn for enumeration under a microscope. Dry weight is determined by drying and weighing the algal sample, then igniting the sample to burn off the algal materials, leaving inert inorganic materials that are again weighed. The difference between initial weight and weight after ignition is attributed to algae.

Any organic sediments, however, that settle on the artificial substrate along with the algae are processed also. Thus, if organic wastes are present appreciable errors may enter into this method.

3 During the past decade, chlorophyll analysis has become a popular method for estimating algal growth. Chlorophyll is extracted from the algae and is used as an index of the quantity of algae present. The advantages of chlorophyll analysis are rapidity, simplicity, and vivid pictorial results.

The algae are scrubbed from the artificial substrate samples, ground, then each sample is steeped in equal volumes, 90% aqueous acetone, which extracts the chlorophyll from the algal cells. The chlorophyll extracts may be compared visually.

Because the chlorophyll extracts fade with time, colorimentry should be used for permanent records. For routine records, simple colorimeters will suffice. At very high chlorophyll densities, interference with colorimetry occurs, which must be corrected through serial dilution of the sample or with a nomograph.

4 Autotrophic Index

The chlorophyll content of the periphyton is used to estimate the algal biomass and as an indicator of the nutrient content (or trophic status) or toxicity of the water and the taxonomic composition of the community. Periphyton growing in surface water relatively free of organic pollution consists largely of algae, which contain approximately 1 to 2 percent chlorophyll a by dry weight. If dissolved or particulate organic matter is present in high concentrations, large populations of filamentous bacteria, stalked protozoa, and other nonchlorophyll bearing microorganisms develop and the percentage of chlorophyll a is then reduced. If the biomass-chlorophyll a relationship is expressed as a ratio (the autotrophic index), values greater than 100 may result from organic pollution (Weber and McFarland, 1969; Weber, 1973).

$$\text{Autotrophic Index} = \frac{\text{Ash-free Wgt (mg/m}^2)}{\text{Chlorophyll a (mg/m}^2)}$$

VII FACTORS INVOLVED IN DATA INTERPRETATION

Two very important factors in data evaluation are a thorough knowledge of conditions under which the data were collected and a critical assessment of the reliability of the data's representation of the situation.

A Maximum-Minimum Values

The evaluation of physical and chemical data to determine their effects on aquatic organisms is primarily dependent on maximum and minimum observed values. The mean is useful only when the data are relatively uniform. The minimum or maximum values usually create acute conditions in the environment.

B Identification

Precise identification of organisms to species requires a specialist in limited taxonomic groups. Many immature aquatic forms have not been associated with the adult species. Therefore, one who is certain of the genus but not the species should utilize the generic name, not a potentially incorrect species name. The method of interpreting biological data on the basis of numbers of kinds and numbers of organisms will typically suffice.

C Lake and Stream Influence

Physical characteristics of a body of water also affect animal populations. Lakes or impounded bodies of water support different faunal associations from rivers. The number of kinds present in a lake may be less than that found in a stream because of a more unifrom habitat. A lake is all pool, but a river is composed of both pools and riffles. The nonflowing water of lake exhibits a more complete setting of particulate organic matter that naturally supports a higher population of detritus consumers. For these reasons, the bottom fauna of a lake or impoundment cannot be directly compared with that of a flowing stream.

D Extrapolation

How can bottom-dwelling macrofauna data be extrapolated to other environmental components? It must be borne in mind that a component of the total environment is being sampled. If the sampled component exhibits changes, then so must the other interdependent components of the environment. For example, a clean stream with a wide variety of desirable bottom organisms would be expected to have a wide variety of desirable bottom fishes; when pollution reduces the number of bottom organisms, a comparable reduction would be expected in the number of fishes. Moreover, it would be logical to conclude that any factor that eliminates all bottom organisms would eliminate most other aquatic forms of life.

VII IMPORTANT ASSOCIATED ANALYSES

A The Chemical Environment

1 Dissolved oxygen

2 Nutrients

3 Toxic materials

4 Acidity and alkalinity

5 Etc.

B The Physical Environment

1 Suspended solids

2 Temperature

3 Light penetration

4 Sediment composition

5 Etc.

IX AREAS IN WHICH BENTHIC STUDIES CAN BEST BE APPLIED

A Damage Assessment

If a stream is suffering from pollutants, the biota will so indicate. A biologist can determine damages by looking at the "critter" assemblage in a matter of hours. Usually, if damages are not found, it will not be necessary to alert the remainder of the agency's staff, pack all the equipment, pay travel and per diem, and then wait five days before enough data can be assembled to begin evaluation.

B By determining what damages have been done, the potential cause "list" can be reduced to a few items for emphasis and the entire "wonderful worlds" of science and engineering need not be practiced with the result that much data are discarded later because they were not applicable to the problem being investigated.

C Good benthic data associated with chemical, physical, and engineering can be data used to predict the direction of future changes and to estimate the amount of pollutants that need to be removed from the waterways.

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Descriptors:
Aquatic Life, Benthos, Water Quality, Degradation, Environmental Effects, Trophic Level, Biological Communities, Ecological Distributions